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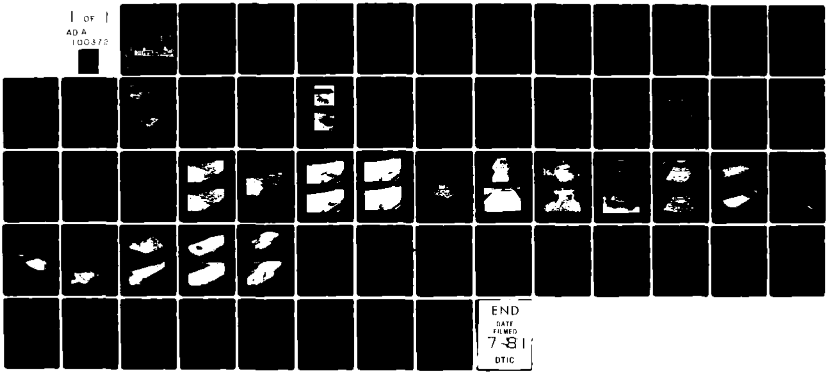

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TECHNICAL REPORT HL-81-3

CHANNEL CONTROL STRUCTURES FOR SOURIS RIVER, MINOT, NORTH DAKOTA

Hydraulic Model Investigation

by

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Final Report

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Model tests of channel control structures constructed of concrete and gabions were conducted at an undistorted scale ratio of 1:12 to determine the discharge characteristics of the structures, size and extent of riprap required to prevent scour downstream of the structures, effects of ice flowing over the structures, and stability of the gabion structures.

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20. ABSTRACT (Continued).

The gabion structure (type I) was located in a typical section of trapezoidal channel and a stable gabion configuration was developed by extending the gabions farther up the side slopes and farther downstream of the structure than was indicated in the original design.

The concrete structure (type III) was placed in an expanded section of trapezoidal channel with riprap protection on the side slopes and on the channel bottom upstream and downstream of the structure. Model results indicated that the original size and extent of protection could be reduced without endangering the structure.

Free and submerged flow discharge characteristics were determined for both types of channel control structures tested, and stability criteria were developed for the gabion structures.

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PREFACE

The model study of the channel control structures for the Souris River Flood Control Project was authorized by the Office, Chief of Engineers, U. S. Army, on 2 March 1973, at the request of the U. S. Army Engineer District, St. Paul. The study was conducted during the period March 1973 to May 1974 at the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Messrs. T. E. Murphy and J. L. Grace, Jr., former and current Chiefs of the Hydraulic Structures Division, and under the supervision of Messrs. J. L. Grace, Jr., and N. R. Oswalt, former and current Chiefs of the Spillways and Channels Branch. The Project Engineer for the model study was Mr. P. E. Saunders, assisted by Messrs. B. P. Fletcher, E. S. Melsheimer, B. Perkins, and W. A. Walker. This report was prepared by Messrs. Grace and Saunders.

During the course of the study, Messrs. R. G. Fast, W. L. Goetz, P. A. Fischer, and J. D. Larson of the St. Paul District and Mr. G. B. Staley of the North Central Division visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with concurrent design work.

Commanders and Directors of WES during the conduct of the study and the preparation and publication of this report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres

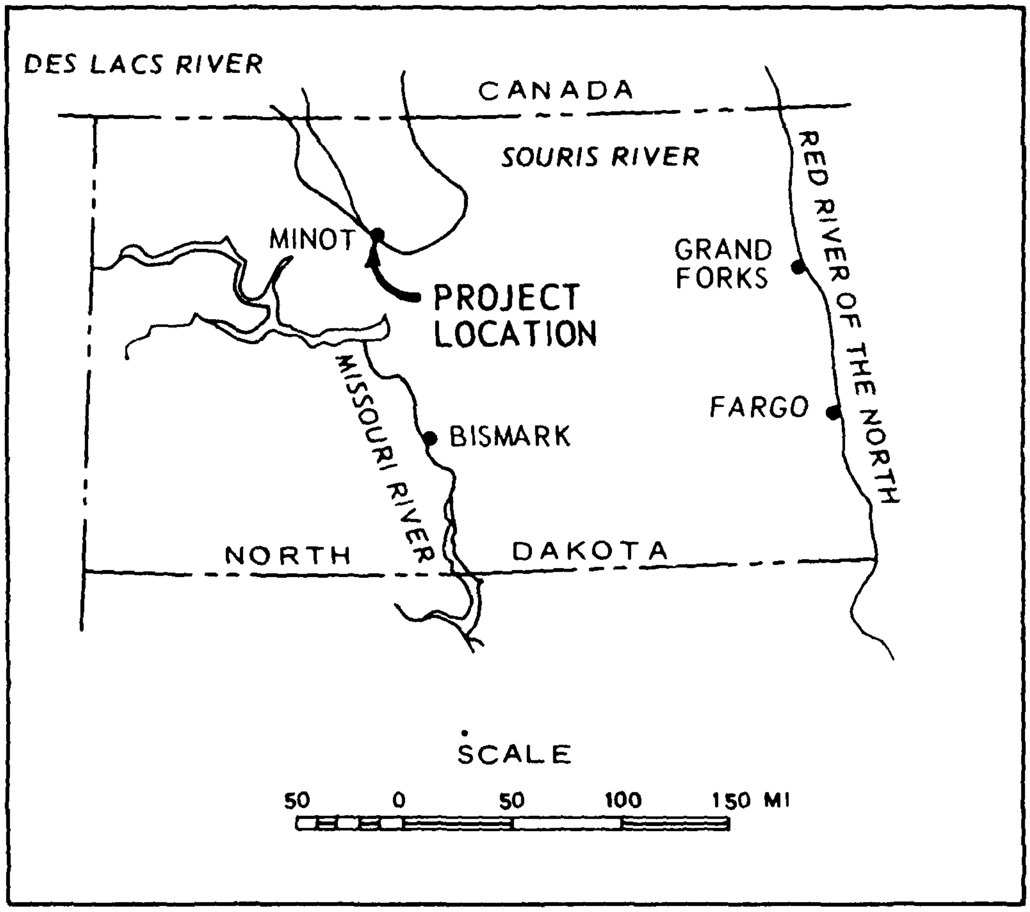

Figure 1. Project location

CHANNEL CONTROL STRUCTURES FOR SOURIS RIVER
MINOT, NORTH DAKOTA

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Souris River Flood Control Project extends from Burlington, North Dakota, through the city of Minot to Logan, North Dakota, a distance of approximately 40 river miles* (Figure 1). The project consists of numerous channel barriers, levees, side inlets, and channel control structures. Two types of structures that are typically placed in straight or slightly curved cutoff channels to control low flows were modeled in this study.

2. The gabion structures (type I) will be located in a trapezoidal channel with 1V-on-3H side slopes and a bottom width of 40 ft. The type I structures will consist of earth fill covered with gabions (gabions are wire baskets that are filled with stone, brick, broken concrete, etc., and fastened together to provide erosion protection, Figure 2). The crest height of the typical type I control structure (Figure 3) will be 6.2 ft above the channel invert. The structure will have an upstream face slope of 1V on 4H and a downstream slope of 1V on 6H. A 1-ft-high end sill will be provided by placing a row of 3-ft-thick gabions across the structure at a position 9 ft downstream from the toe of the downstream slope.

3. The concrete structures (type III) will be located in expanded transition sections that diverge upstream and converge downstream at a rate of 1 in 10 to trapezoidal channels with 1V-on-3H side slopes and bottom widths of 40 ft. Riprap protection will be provided on the side

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

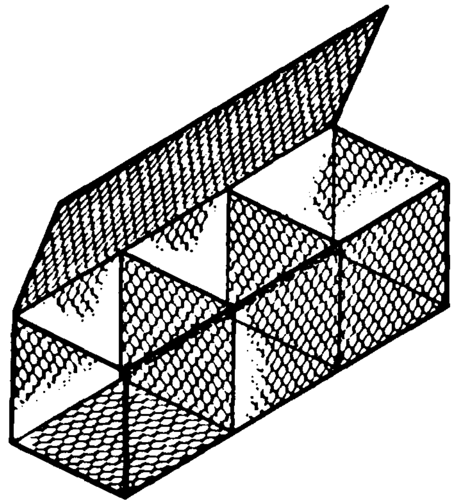

Figure 2. A gabion basket

slopes and downstream of the type III structures. The typical type III structure (Figure 4) will consist of a concrete weir with a crest located 10.0 ft above the channel bottom with a 1-ft-high end sill at the end of a 25-ft-long stilling basin. A wet well, a sluice gate, and a 4- by 5-ft conduit will be provided to bypass and control release of low flows around the weir.

4. The type I and III structures were both designed as low-water weirs rather than grade-control structures, and therefore, the channel invert elevation will be the same upstream and downstream of the structures. The design discharges for the type I and III structures (project structures 8 and 16, respectively) were 5,280 cfs and 5,000 cfs, respectively. These flows would result from a flood with a 100-year recurrence interval after construction of the proposed Burlington Reservoir. Prior to completion of the Burlington Reservoir, the 100-year frequency flood flow would be about 14,000 cfs. This discharge would cause overbank flow, which was also investigated in the model.

Purpose of Model Study

5. The purpose of the model study was to develop reliable design

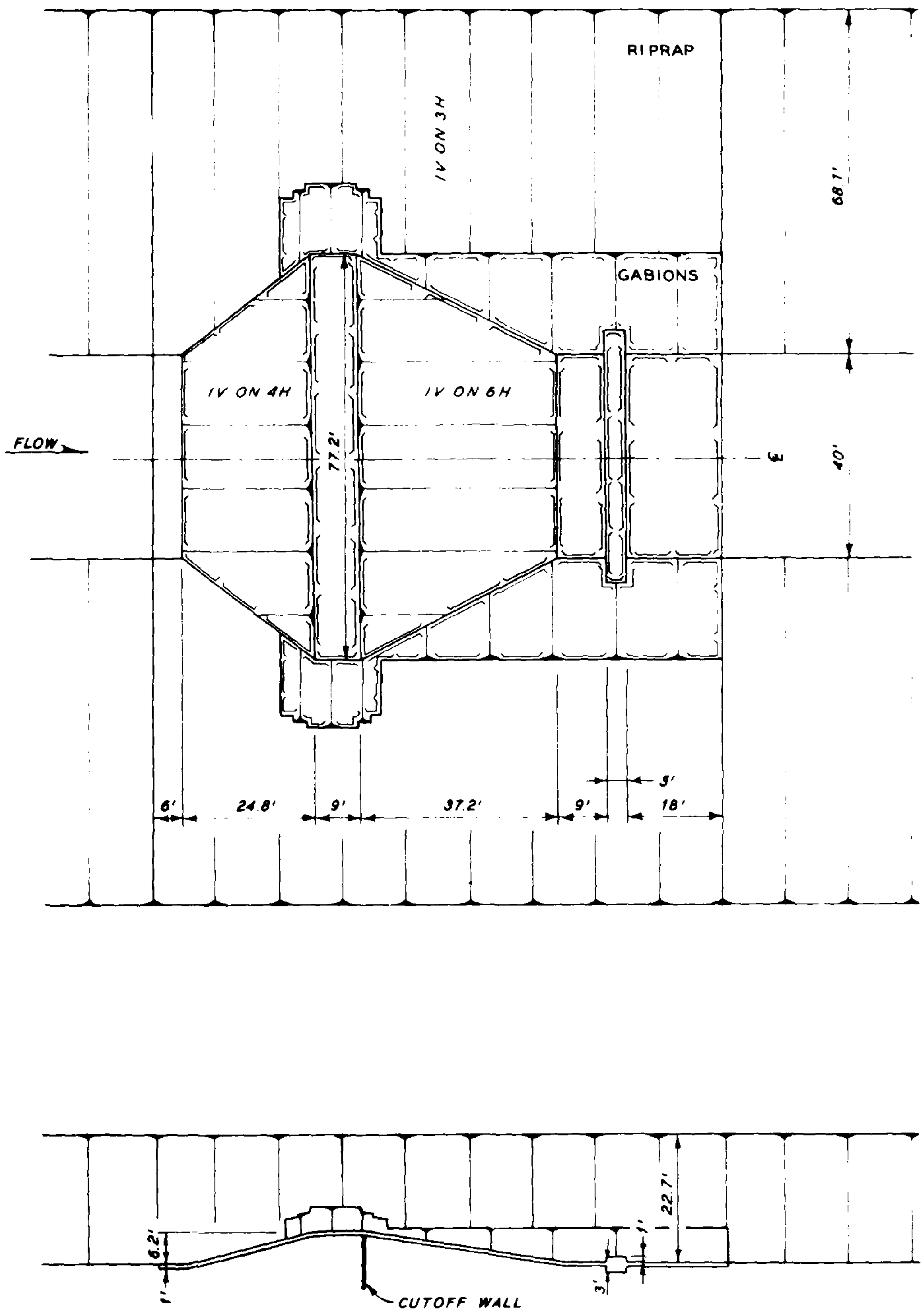

Figure 3. Type I channel control structure (typical structure 6.2 ft high)

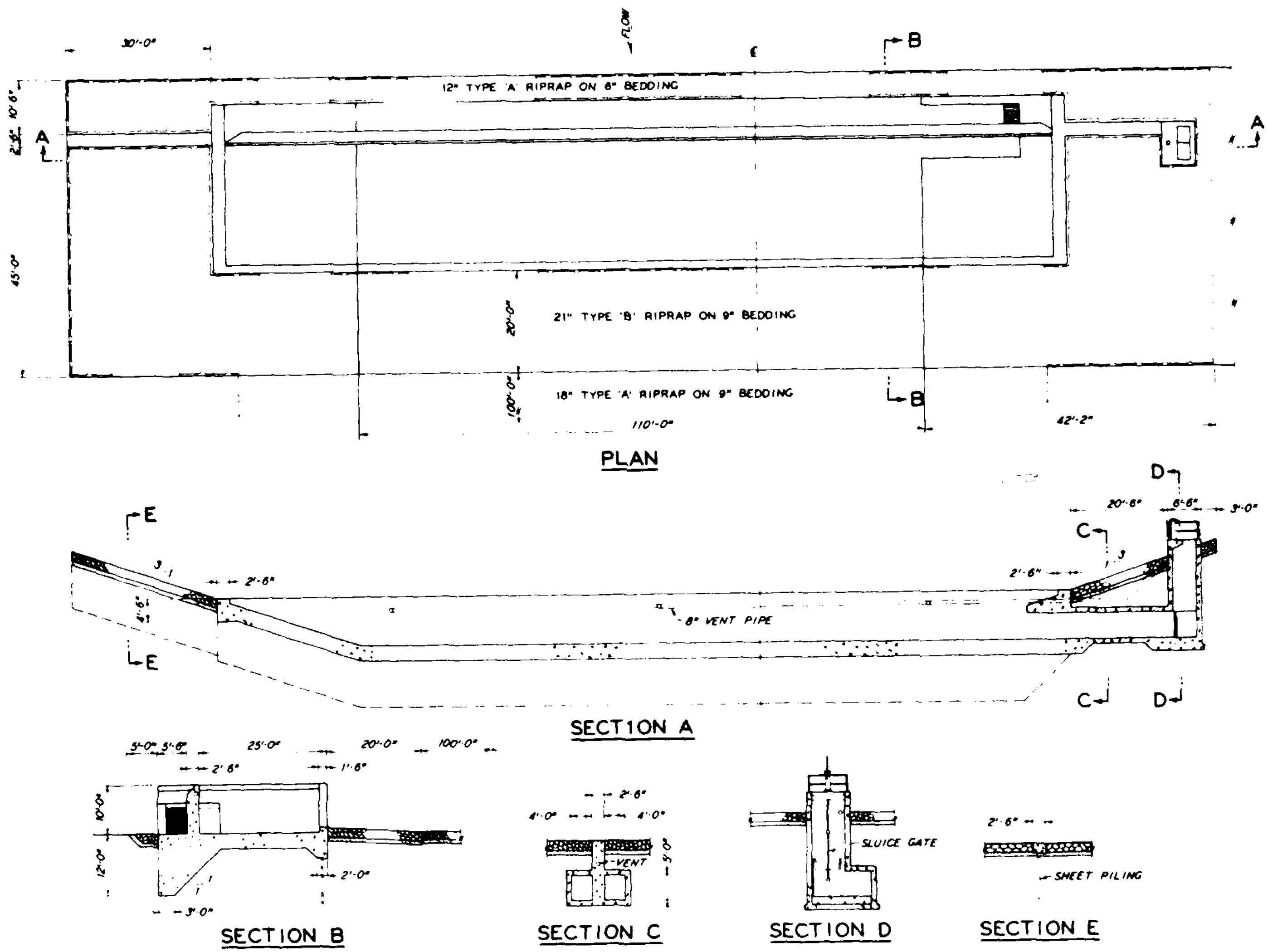

Figure 4. Original design type III channel control structure

criteria for the proposed control structures. This included determination of the discharge characteristics of the two types of control structures, the stability of an individual and preselected minimum size of gabion, and the size and extent of loose riprap protection required to withstand the impact of various masses of floating ice on both types of structures. The effect of overbank flow on the overall hydraulic performance of the structures was also investigated. A limited attempt was made to develop generalized guidance relative to the discharge characteristics and stability of gabion-constructed control structures.

PART II: THE MODEL

Description

6. Both control structures were modeled to an undistorted scale ratio of 1:12. The models reproduced a straight channel section extending 300 ft upstream and 540 ft downstream of the axes of the structures. The model of the type III structure (Figure 5) was constructed of plywood. The wet well, gate, and conduit used for low-flow control were constructed of plastic. The model of the type I structure (Figure 6) was constructed using a cutoff wall covered with sand, a curtain lining material to act as a filter fabric and prevent leaching of the sand, a layer of pea gravel simulating a 9-in.-thick filter layer, and gabions. The model gabions were simulated with wire baskets (hardware mesh) filled with graded pea gravel. The model simulated 6- by 3- by 1-ft-thick gabions on the upstream slope, 3- by 3- by 1-ft-thick gabions on the downstream slope, and an end sill comprised of 12- by 3- by 3-ft-thick gabions. Both structures were located in a molded sand channel. Wooden blocks were used to simulate blocks of ice with a maximum prototype size of 6 by 4 by 2 ft thick.

7. Water used in the operation of the model was supplied by pumps, and discharges were measured by means of venturi meters. Steel rails set to grade provided reference planes for measuring devices. Water-surface elevations were measured by means of point gages. Current patterns were determined by means of dye injected below the water surface and confetti sprinkled on the surface.

Scale Relations

8. The accepted equations of hydraulic similitude, based upon the Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype. The general relations expressed in terms of the undistorted model scale or length ratio, L_r, are presented in the following tabulation:

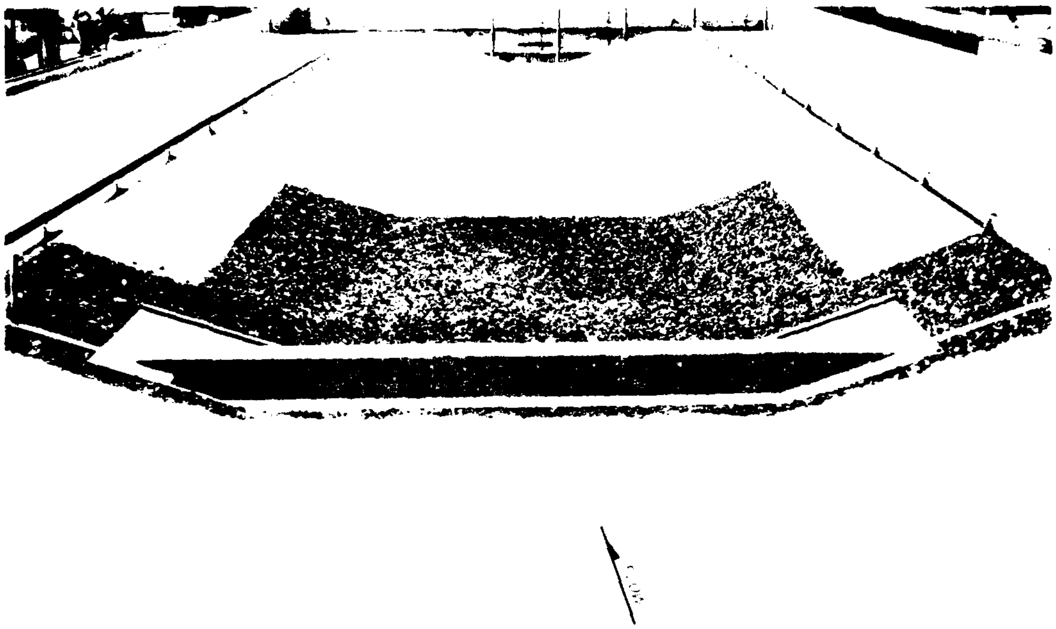

Figure 5. 1:12-scale model of type III control structure (concrete)

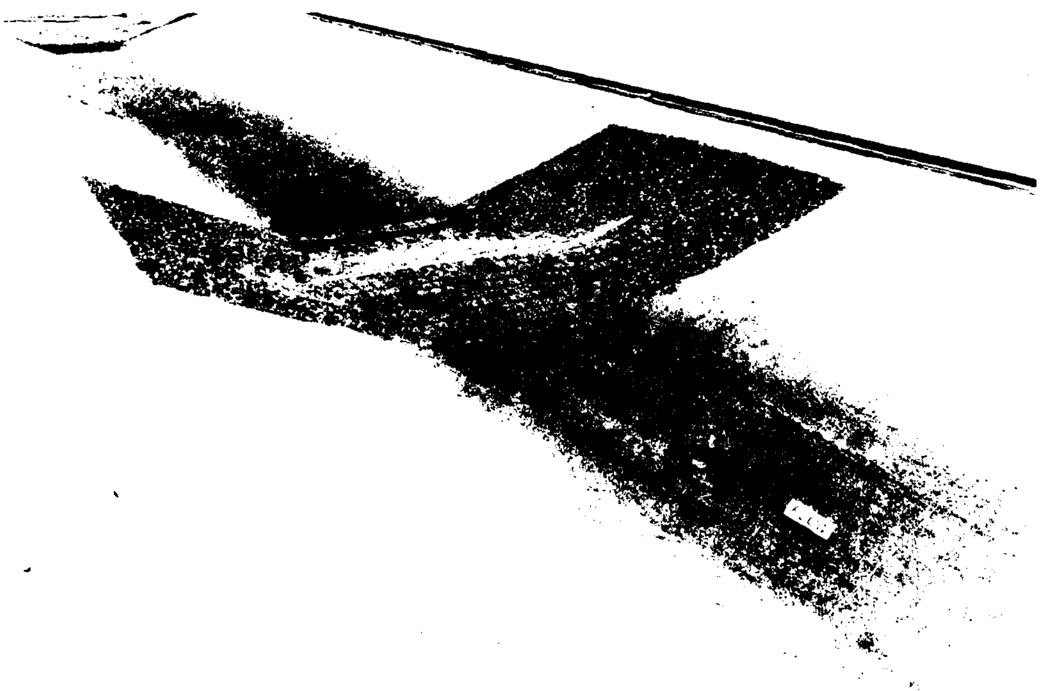

Figure 6. 1:12-scale model of type I control structure (gabions)

Dimension	Ratio	Scale Relation
Length	L_r	1:12
Area	$A_r = L_r^2$	1:144
Velocity	$V_r = L_r^{1/2}$	1:3.464
Discharge	$Q_r = L_r^{5/2}$	1:498.8
Time	$T_r = L_r^{1/2}$	1:3.464

9. Measurements of discharge, water surface, and depths of flow can be transferred quantitatively from the model to prototype by means of the preceding relations.

PART III: TESTS AND RESULTS

Type III Structure

10. The normal approach channel bottom width of 40 ft will expand through a 1-to-10 transition to a bottom width of 110 ft, where the type III concrete structure (Figures 4 and 5) will be located. The base width of the exit area is contracted in a similar manner to the normal channel base width of 40 ft. The increased width of the structure, relative to the channel, was effective in preventing significant head differential and damage to the structure with overbank flow conditions. The weir crest will be located 10 ft above the invert of the approach channel.

11. The type III structure will have a bypass conduit to drain the upstream pool during low-flow periods, and a gate well structure to control the flow through the conduit (Figures 4 and 5). The stilling basin and the downstream riprap protection were designed for much greater discharges than the capacity of the conduit. Low-flow situations were satisfactory in the model. The conduit discharge was not sufficient to adversely affect flow patterns with larger discharges over the weir.

12. Due to the harsh winter climate of North Dakota, model-testing of possible ice damage was desired. Wooden blocks were used to simulate the ice flows present during spring floods. Transport of the simulated ice over the crest of the structure was initiated with a discharge of approximately 250 cfs. However, general transport of all the blocks was not observed until the discharge equaled or exceeded 800 cfs. Although many ice blocks remained trapped in the basin and were continuously rolled over with free flow conditions, they did not strike against or tend to abrade the structure. Photographs of various flow conditions through the type III structure with ice simulated by wooden blocks are presented as Photos 1 and 2. During free flow conditions, the flow passing over the weir plunged into the stilling basin and created a roller action, which trapped some blocks of ice in the basin and caused them to occasionally impact against the downstream side of the weir (Photo 1c). Photographs of low flows through two of the prototype structures are shown in Figure 7.

Figure 7. Low-flow conditions through two of the Souris River channel control structures constructed of gabions

13. By analyzing the basic calibration data (Plate 1) obtained from the model in a manner similar to that followed in an earlier study of an ogee crest spillway,* it was possible to define the conditions required for free flow and submerged flow (Plate 2). Having distinguished the two flow regimes, it was then possible to apply the usually accepted equations for weir flow.**

Free flow:

$$Q = CL'H^n \quad \text{or} \quad Q = C(L + ZH)H^n$$

Submerged flow:

$$Q = C_s A\sqrt{2g\Delta H}$$

where

Q = discharge in cfs

C = free flow discharge coefficient

L' = average width of flow over crest

Free flow $L' = L + ZH$

Submerged flow $L' = L + Zh$

L = base length of weir crest

Z = ratio of horizontal to vertical components of the side slope of the weir

H = gross head on weir crest

h = tailwater depth above weir crest

n = exponent

C_s = submerged flow discharge coefficient - function of submergence (h/H)

A = flow area over weir (see Plate 16) based on average width of flow and tailwater above the weir crest = $(L + Zh)h$

g = acceleration due to gravity

ΔH = water-surface differential over the weight $(H - h)$

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* J. L. Grace, Jr. 1963 (Sep). "Typical Spillway Structure for Central and Southern Florida Water-Control Project; Hydraulic Model Investigation," Technical Report 2-633, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** Horace, W. King. 1954. Handbook of Hydraulics, McGraw Hill Book Company, New York.

14. Results of the analysis of the free and submerged flow discharge characteristics are shown in Plates 3-5. Least-squares fits of the data produced the following equations for description of free flow discharge characteristics of the type III structure:

$$Q = 3.63\ L\ H^{1.63} \quad \text{(see Plate 3)} \tag{1}$$

$$q = 3.64\ H^{1.59} \quad \text{or}$$

$$Q = 3.64\ (L + 3H)\ H^{1.59} \quad \text{(see Plate 4)} \tag{2}$$

15. Free flow in the type III structure was characterized by a roller that was contained within the stilling basin (Photos 1a-1c). Submerged flow consisted primarily of a surface jet of flow with and without standing waves over relatively calm lower depths (Photos 2a-2d). There were no occurrences of riprap displacement upstream of the weir where the velocities were relatively low. The downstream flow patterns indicated concentration of flow in the center of the channel which aided in preventing damage of the riprap protection due to ice hitting the channel banks. The model indicated that the riprap requirements could be reduced relative to those proposed in the original design (Plate 6). The recommended design eliminated 100 ft of protection along the channel bottom but required a greater length of protection along the sides of the channel and reduced the riprap size in almost all areas. Exit channel scour was minimal with discharges as large as 4,000 cfs and tailwaters 3.5 ft lower than anticipated.

Typical Type I Structure

16. The typical type 1 gabion structure will be constructed in a trapezoidal channel section with a 40-ft bottom width (Figures 3 and 6). Because the crest height of the typical gabion structure modeled was only 6.2 ft above the channel invert, compared with a total channel depth of 22.7 ft, it was not necessary to widen the channel in order to

accommodate the design discharge without excessive head loss that could cause flanking of the structure as was required with the type III structure. The model study indicated a greater tendency for overbank flow to concentrate and tend to flow through the center of the type I structure than occurred with the type III structure. The expected tailwater, however, was sufficiently high to prevent damage to the riprap protection during these flow conditions. However, sufficient length of protection to prevent development of a local scour hole immediately downstream is required.

17. The effect of the spring breakup of ice cover was also studied with the typical type I gabion structure. The end sill of the type I structure (prototype) will be composed of 12- by 3- by 3-ft gabions, recessed into the ground so that they form a 1-ft-high end sill. When this end sill was modeled with wire baskets simulating 6- by 3- by 1-ft-thick gabions, the impact of ice blocks at low tailwater caused failure of the end sill (Photo 3). Therefore, the end sill should be constructed of 3-ft-thick gabions as originally planned and as shown in Figure 3a.

18. The basic calibration data of the typical type I structure (Plate 7) was compared with the results of a model study of overflow embankments along the Arkansas River* to ascertain the flow regimes for this type of weir. The distinction between free and submerged flow (Photo 4) is shown in Plate 8. The free and submerged flow characteristics were analyzed with the same three equations used in the analysis of the type III structure. The results of the free flow analysis of the typical type I structure (6.2 ft high) yielded the following equations:

$$Q = 2.79\ LH^{1.63} \quad \text{(see Plate 9)} \tag{3}$$

$$q = 2.59\ H^{1.54} \quad \text{or} \quad Q = 2.59\ (L + 3H)\ H^{1.54} \quad \text{(see Plate 10)} \tag{4}$$

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* N. J. Brodgon, Jr., and J. L. Grace, Jr. 1964 (Jun). "Stability of Riprap and Discharge Characteristics, Overflow Embankments, Arkansas River, Arkansas; Hydraulic Model Investigation," Technical Report 2-650, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

These equations are similar to those for the type III structure. However, the submerged flow characteristics of the type I structure (Plate 11) appear to be markedly different from the submerged flow characteristics of the type III structure (Plate 5). The type I and III structures enter a submerged flow regime at submergences of about 80 and 40 percent, respectively. This is in good agreement with other broad- and sharp-crested weirs.

19. Early testing of the typical type I structure indicated that the size of the riprap protection proposed around the gabions (Figure 8) was not adequate (Photo 5). Significant scour also developed downstream of the recommended structure (Photo 6). As a result, the downstream gabion protection was extended up the side slopes to the elevation of the weir crest and 9 ft farther downstream into the exit channel (Figure 9). These modifications resulted in satisfactory performance of the typical type I gabion-constructed structure for all anticipated discharges and tailwaters.

General Gabion Structures

20. Extensive local scour and degradation of the sand channel resulted during the model tests conducted to develop stability criteria for the typical type I gabion control structures, as shown in Photo 6. This degradation permitted tailwater levels to be about 5 ft less than the anticipated levels in the model exit channel. However, the gabion type protection could not be failed in a 40-ft-wide channel. In order to obtain generalized discharge characteristics and stability criteria for the gabion-constructed control structures, narrower fixed-bed channels (base widths of 20 and 10 ft) were constructed so that turbulence and velocities sufficient to move the gabions could be created.

21. Nine additional tests were conducted to obtain generalized design guidance for gabion structures with crest heights of 6.2, 9, and 12 ft above the invert of trapezoidal-shaped exit channels with 1V-on-3H side slopes; channel bottom widths of 10 and 20 ft, and approach channel inverts 3, 5, and 9 ft above the downstream channel invert elevation

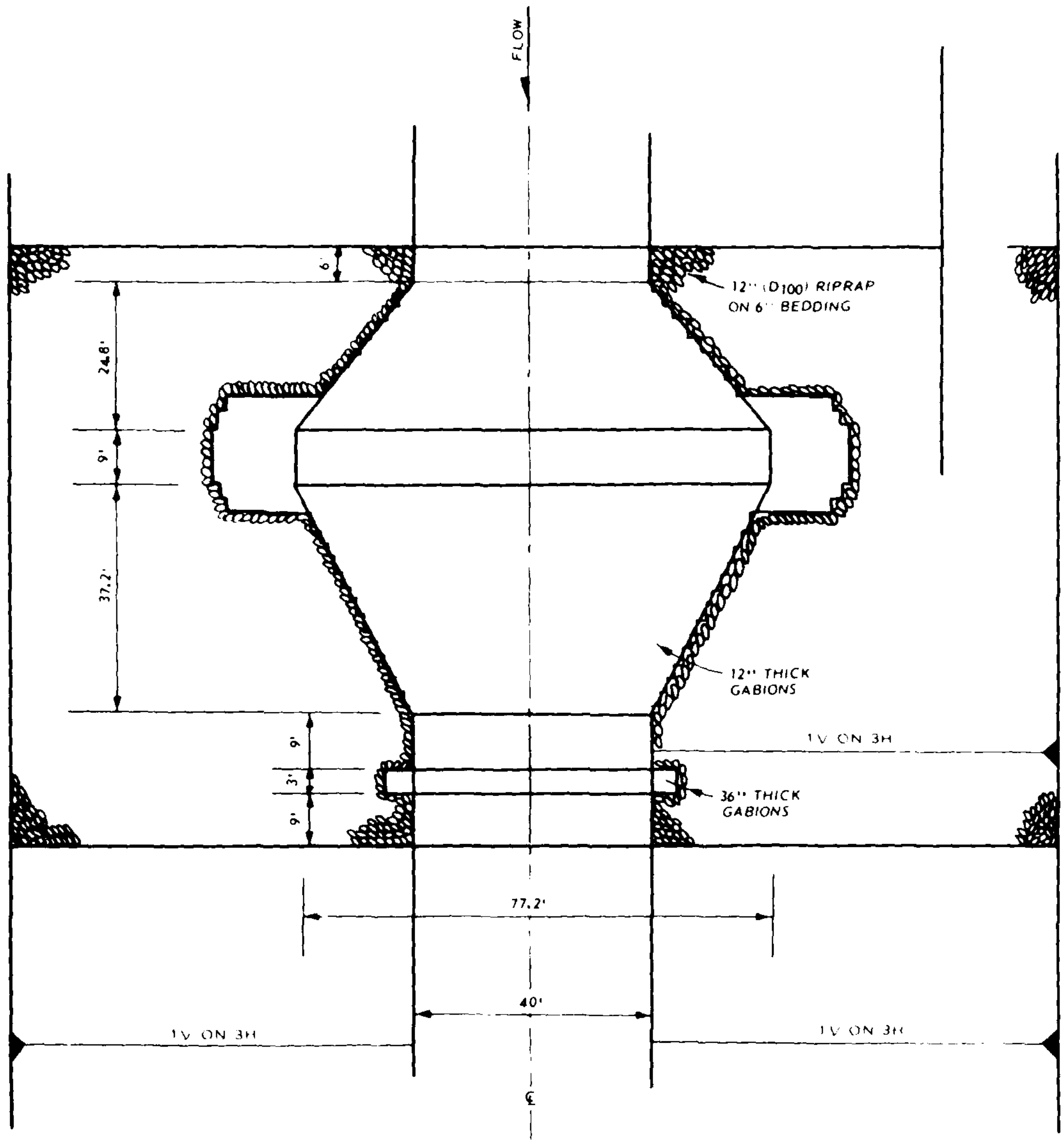


Figure 8. Gabion and riprap protection proposed originally for typical type I structure

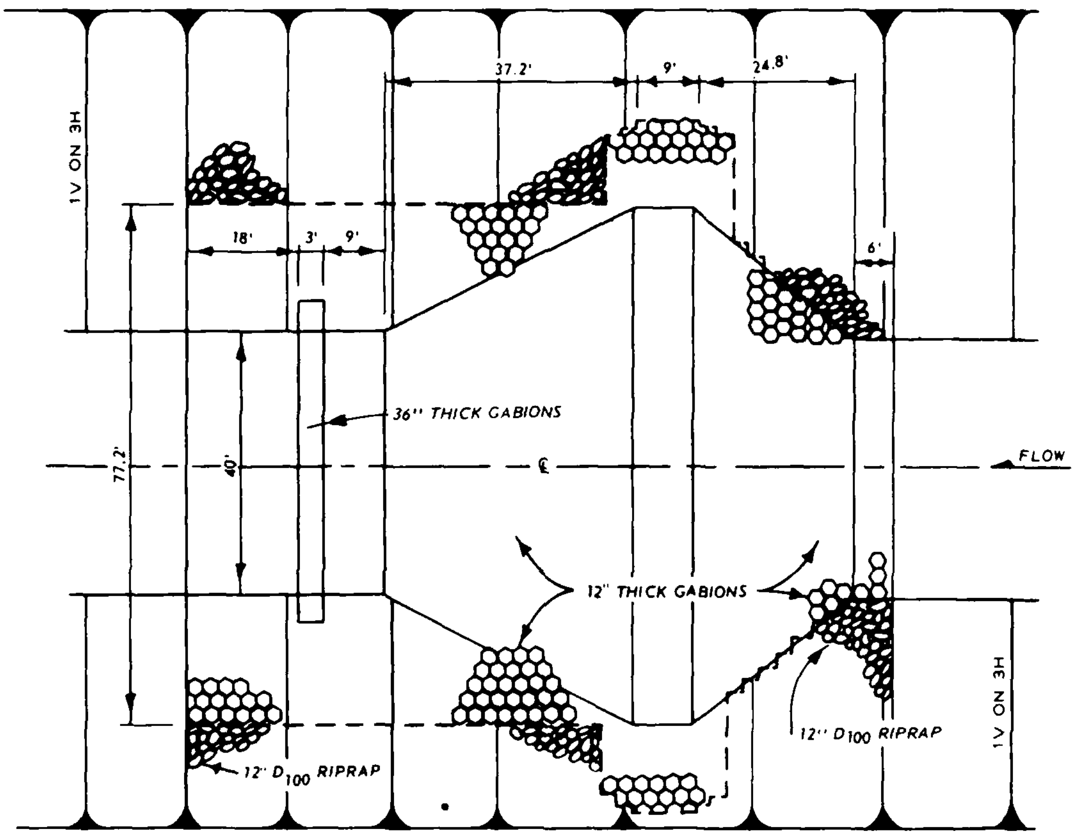


Figure 9. Recommended gabion and riprap protection for typical type I structure (6.2 ft high)

(Photos 7-15). The discharge characteristics of the various structures were analyzed in the same manner as those for the typical type I structure. Flow regimes distinguished from all tests are shown in Plate 12.

22. In these series of tests it was possible to obtain free flow data with a broader range of discharges and head differentials because of the use of a fixed-bed channel in the model. These additional data made it possible to develop more accurate equations for describing the discharge characteristics of gabion-constructed channel control structures. Plate 13 demonstrates the good correlation obtained with the free flow data of the nine tests which can be described by the equation:

$$q = 2.63\ H^{1.62}$$

or

$$Q = 2.63\ (L + 3H)\ H^{1.62} \tag{5}$$

23. The scatter of data for the submerged flow tests of the type I structures with a movable-bed channel is shown in Plate 11. The scatter of data in Plate 14 illustrates that obtained with submerged flow tests and a fixed-bed channel. The data indicate that the submerged flow discharge coefficient remains essentially constant at a value of 1.25. The submerged flow discharge characteristics of the gabion-constructed structures in trapezoidal channels with 1V-on-3H side slopes can be described by the equation

$$Q = C_s\ A\sqrt{2g\Delta H} \tag{6}$$

where C_s, the submerged flow discharge coefficient, remains essentially constant at a value of 1.25 and $A = (L + 3h)\ h$. The approach channel invert elevation had no significant effect on the discharge characteristics of the structures investigated.

24. Table 1 defines the conditions under which failure of the gabion protection was observed. The nature of the failure observed in

various tests is shown in Photo 16. The failures were induced by high velocities and curvilinear flow downstream of the weir crests that were sufficient to create excessive uplift and/or hydrostatic pressures under the standing waves in the downstream exit area (Photo 17). The excessive uplift was sufficient to displace the individually simulated gabions (3 by 3 by 1 ft thick) or the excess hydrostatic pressures were sufficient to leach the granular filter and sand through the gabions which then were displaced and eventually swept downstream. The flow conditions that caused failure in the model were found to be highly dependent on the quality of construction and the effectiveness of the filter material.

25. Plate 15 demonstrates the flow conditions under which displacement of the 12-in.-thick gabions occurred in the model and permits selection of flow conditions and geometric characteristics required for stable structures of this type. Also included are the anticipated flow conditions for the type I structure. A sketch defining variables used in Plate 15 is shown in Plate 16.

PART IV: DISCUSSION

26. The hydraulic model investigation of the Souris River channel control structures indicated that the original designs of the type I and III structures were basically adequate with only minor modifications needed for stability under the anticipated flow conditions. The model study confirmed one important design consideration emphasized by the St. Paul District that when overbank flow is expected rather frequently, it is most appropriate to provide a greater length of crest to prevent objectionable head differentials and the resulting potential for severe erosion and flanking of the structure when the overbank is initially flooded.

27. It was possible to greatly reduce the extent and size of riprap with the type III structure. The type I structure, being located in a relatively narrower reach of channel and having higher unit discharges, required increased gabion protection both on the side slopes and the channel bottom.

28. No significant damage to either structure was incurred by flow of ice over the structures or by overbank flow. No significant damage of the recommended protection occurred at any discharge when accompanied by its anticipated tailwater depth.

29. Generalized guidance was developed from model tests of 6.2- to 12-ft-high gabion structures placed within trapezoidal channels with 1V-on-3H side slopes and base widths from 10 to 40 ft. Both free and submerged flow discharge characteristics of the structures were determined (Equations 1, 2, 5, and 6) as well as stability criteria (Plate 15) for the gabion protection.

30. It should be emphasized that the stability of gabions under various flow conditions was found in the field to be dependent on construction methods and control, filter materials, layout of the gabions, and design of the structure. As used in the type I structure, gabions proved to be very stable and quite capable of withstanding the projected flow conditions. Because the prototype gabions will be wired together, it is considered that the model results relative to stability are conservative.

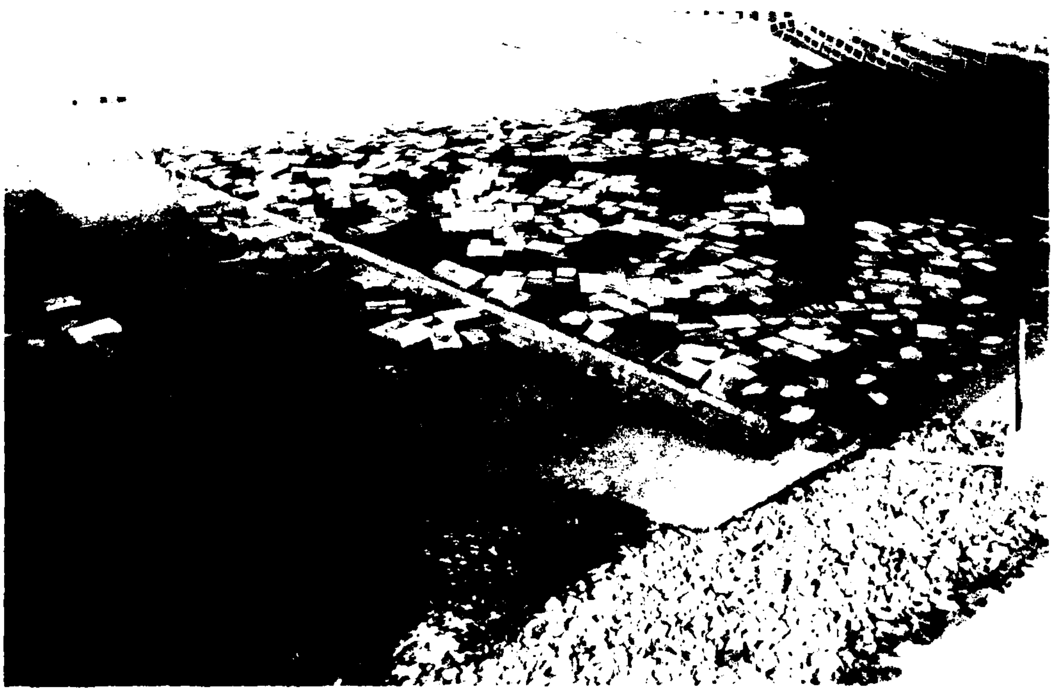
31. Results of this model study may be applied to design gabion-constructed control structures placed within a trapezoidal channel. However, as the results are based on limited model tests, consideration should be given to model-testing similar proposed structures with crest heights greater than 12 ft, flatter or steeper side slopes, or other major geometric deviations from the design tested.

Table 1

Failure Conditions, Gabion Structures

Test No.	Depth of Approach ft	Crest Length ft	Crest Height ft	Total Discharge cfs	Gross Head on Crest ft	Tailwater El Referred to Crest, ft	Unit Discharge, cfs/ft $\frac{Q}{L}$	Unit Discharge, cfs/ft $\frac{Q}{L + 3H}$	Water-Surface Differential, ft ΔH
1	12	92	12	6900	7.37	-0.50	75.0	60.5	7.87
3	6.2	57.2	6.2	5500	7.40	1.77	96.2	69.3	5.63
5	9	64	9	3900	5.62	0.60	60.9	48.2	5.02
5	9	64	9	3900	5.81	-0.90	60.9	47.9	6.71
5	9	64	9	5100	6.64	4.81	79.7	60.8	0.83
5	9	64	9	6000	7.41	4.75	93.8	69.6	2.66
6	12	82	12	6000	6.96	-1.06	73.2	58.3	8.02
9	3	82	12	2000	3.59	-4.49	24.4	21.6	8.08
9	3	82	12	3900	5.23	0.93	47.6	39.9	4.30
9	3	82	12	5100	4.70	1.99	52.2	51.5	3.71
9	3	82	12	6000	6.60	3.96	73.2	58.9	2.64
9	3	82	12	7200	7.35	6.10	87.8	69.2	1.25

a. Discharge 200 cfs

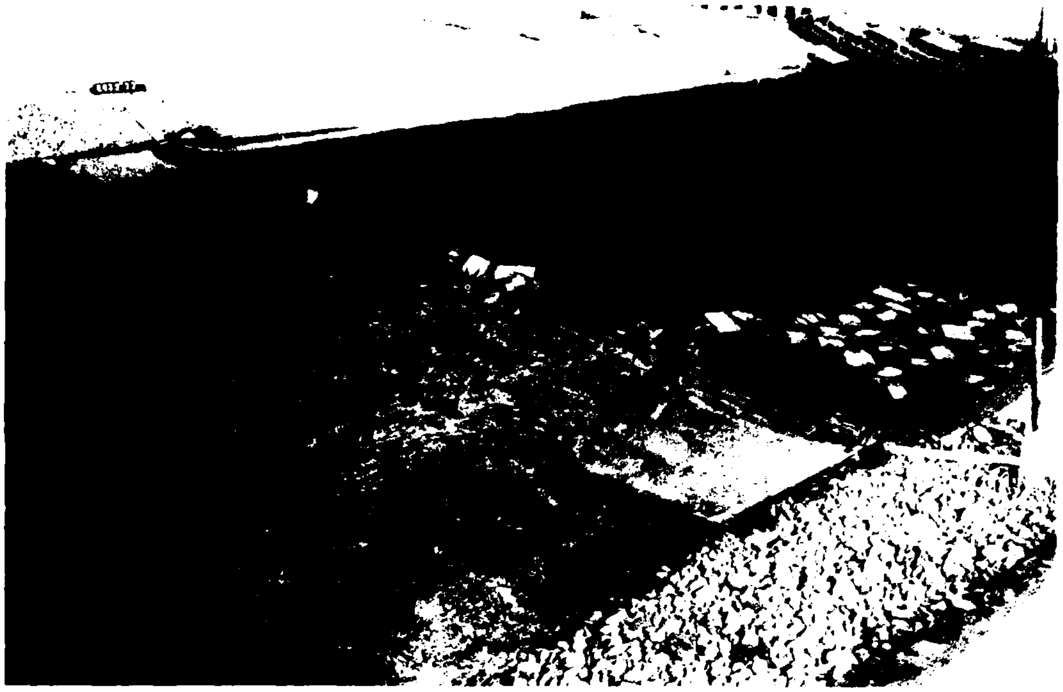


b. Discharge 500 cfs

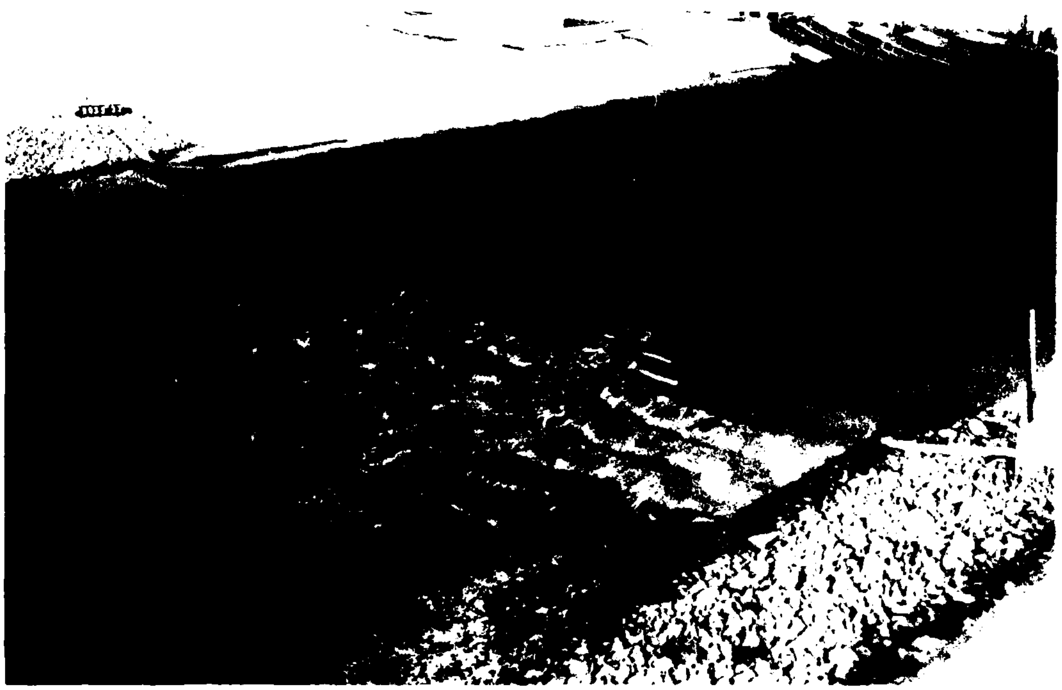
Photo 1. Various free flow conditions in type III structure (Sheet 1 of 2)

c. Discharge 800 cfs

Photo 1. (Sheet 2 of 2)



a. Discharge 1400 cfs



b. Discharge 1970 cfs

Photo 2. Various submerged flow conditions through type III structure (Sheet 1 of 2)

c. Discharge 3900 cfs

d. Design discharge 5280 cfs

Photo 2. (Sheet 2 of 2)

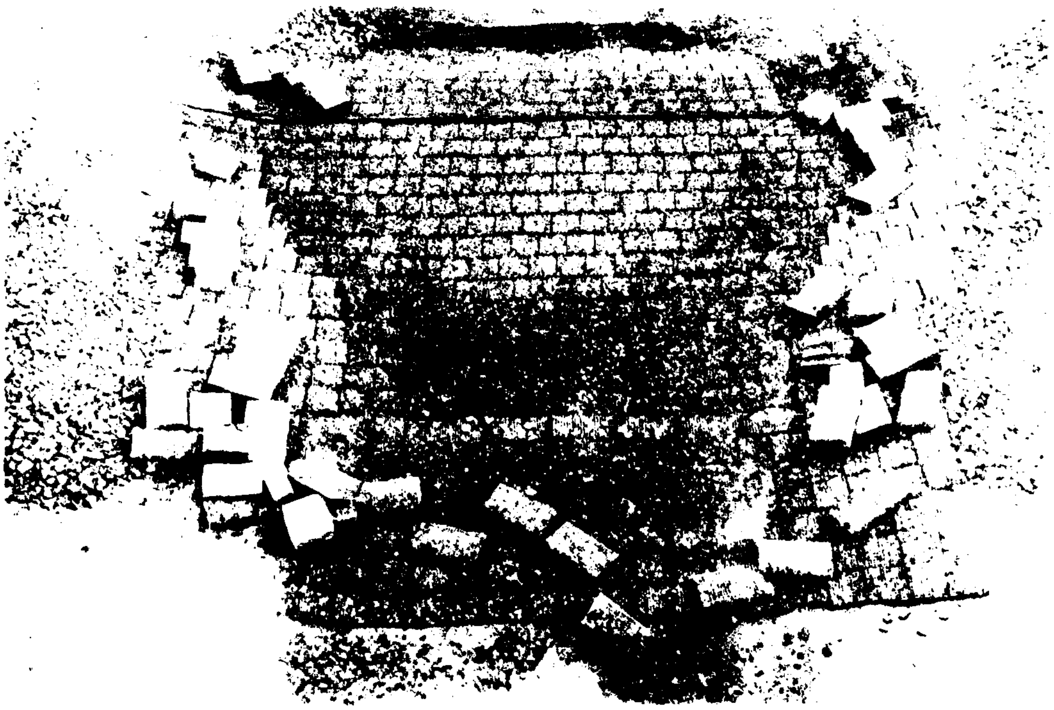


Photo 3. Failure of 6- by 3- by 1-ft gabion-formed end sill

a. Free flow, discharge 140 cfs

b. Submerged flow with design discharge, 5280 cfs

Photo 4. Various flow conditions in type 1 structure

Photo 5. Failure of riprap protection in initial design of type I structure

Photo 6. Local scour and degradation of downstream sand channel

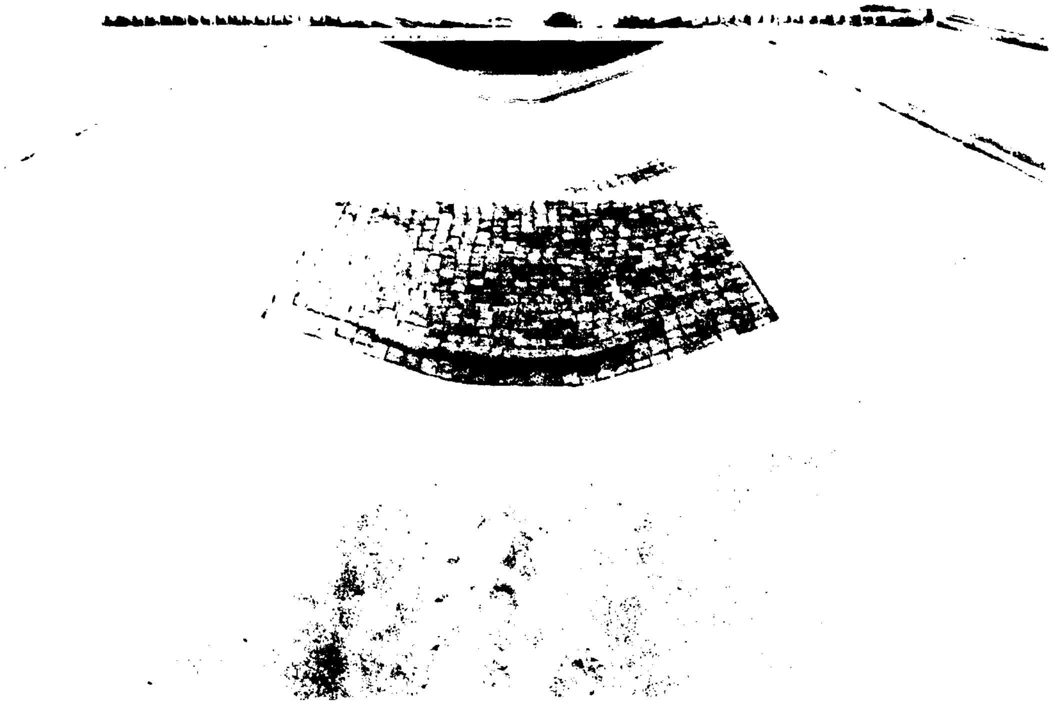


Photo 7. Test 1 conditions: crest height 12 ft, channel width 20 ft, invert el 0.0

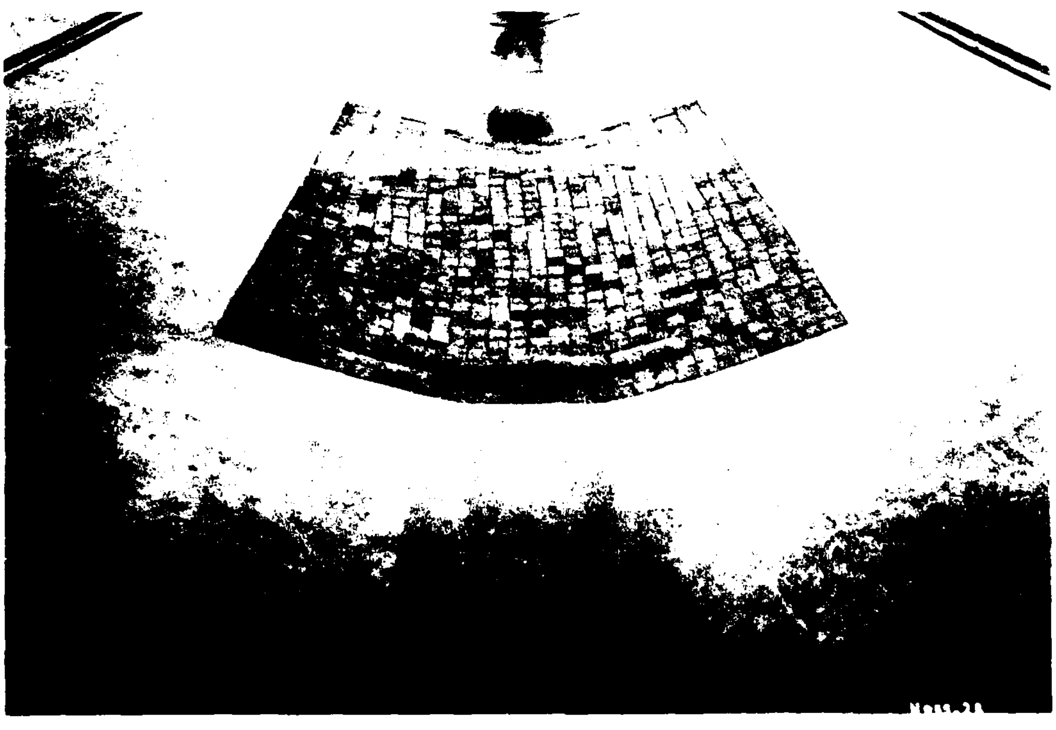


Photo 8. Test 2 conditions: crest height 9 ft, channel width 20 ft, invert el 0.0

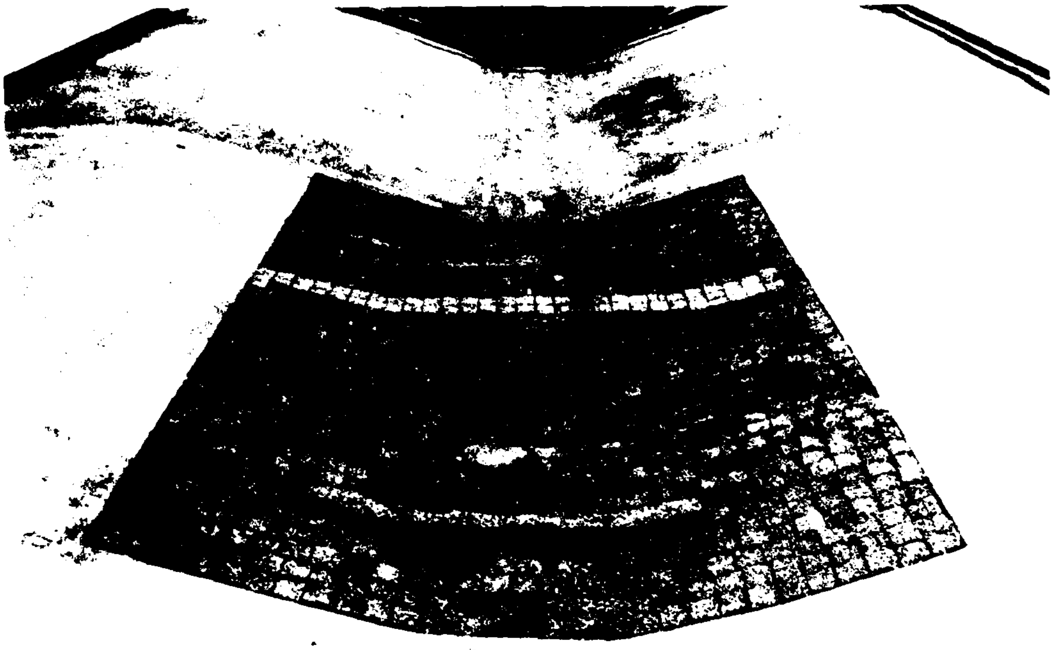


Photo 9. Test 3 conditions: crest height 6.2 ft, channel width 20 ft, invert el 0.0

Photo 10. Test 4 conditions: crest height 6.2 ft, channel width 10 ft, invert el 0.0

Photo 11. Test 5 conditions: crest height 9 ft, channel width 10 ft, invert el 0.0

Photo 12. Test 6 conditions: crest height 12 ft, channel width 10 ft, invert el 0.0

Photo 13. Test 7 conditions: crest height 12 ft, channel width 10 ft, invert el 3.0

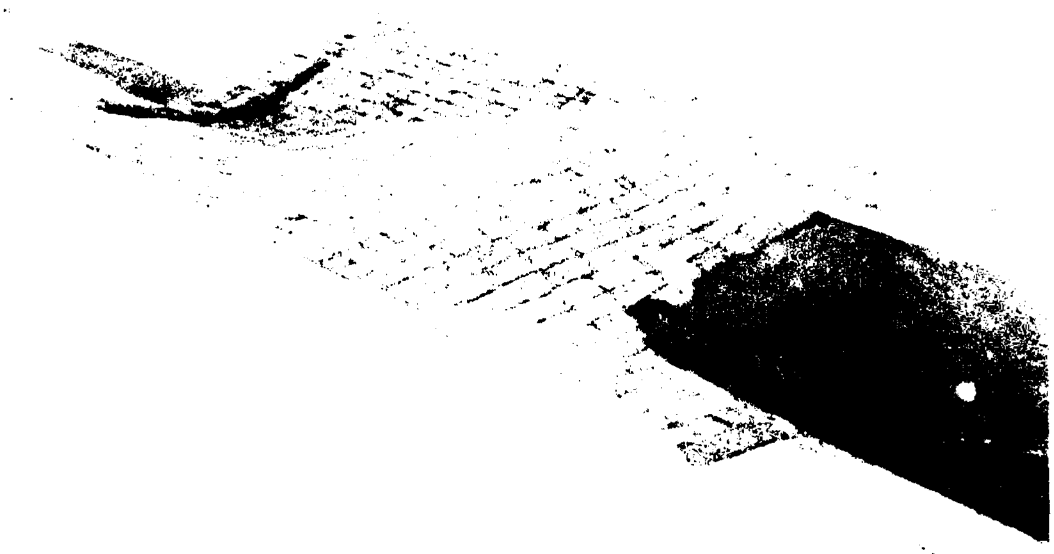


Photo 14. Test 8 conditions: crest height 12 ft, channel width 10 ft, invert el 6.0

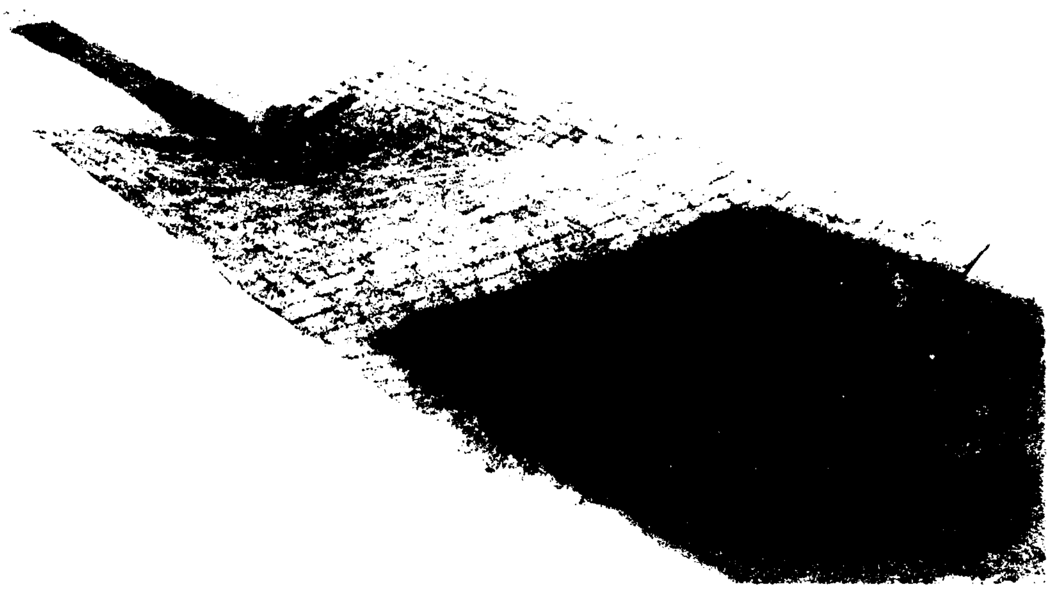
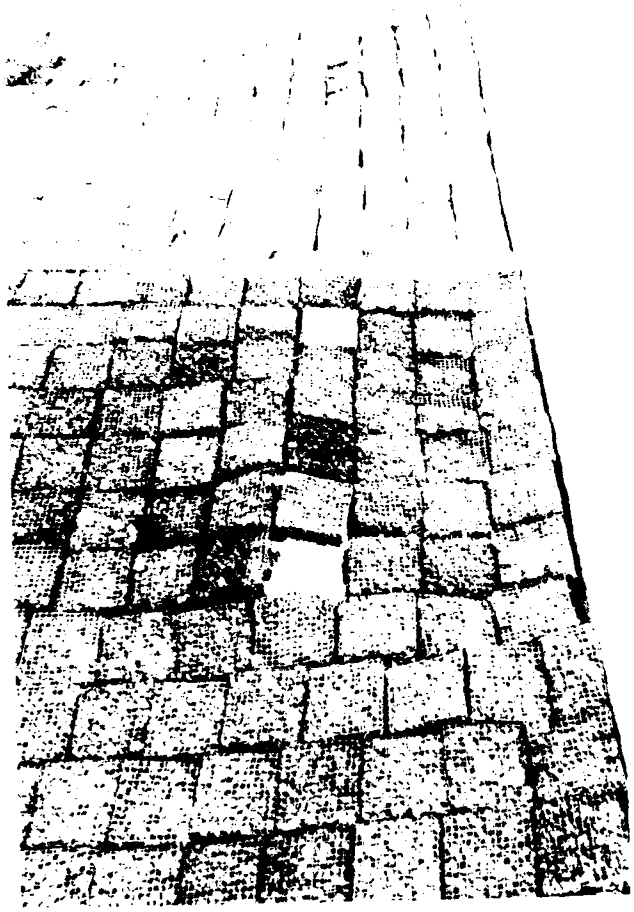
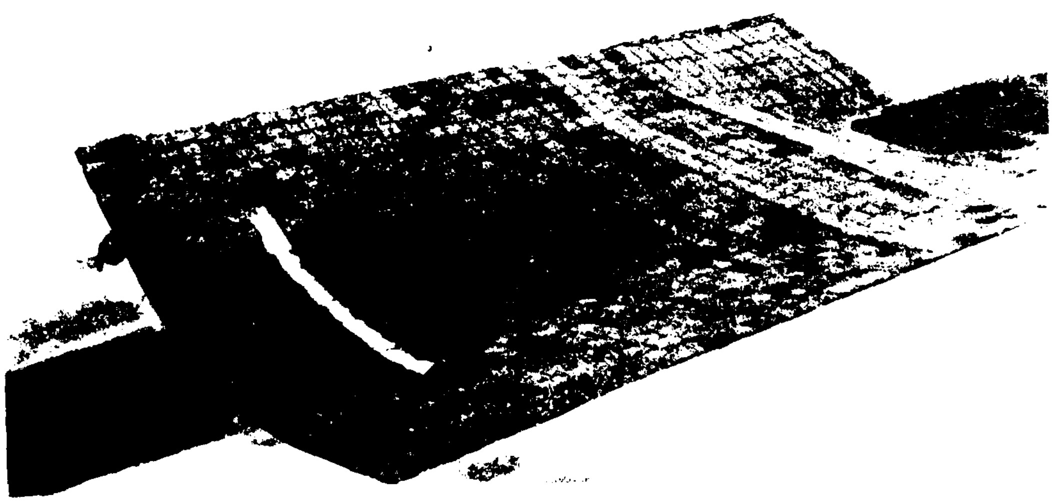


Photo 15. Test 9 conditions: crest height 12, ft, channel width 10 ft, invert el 9.0

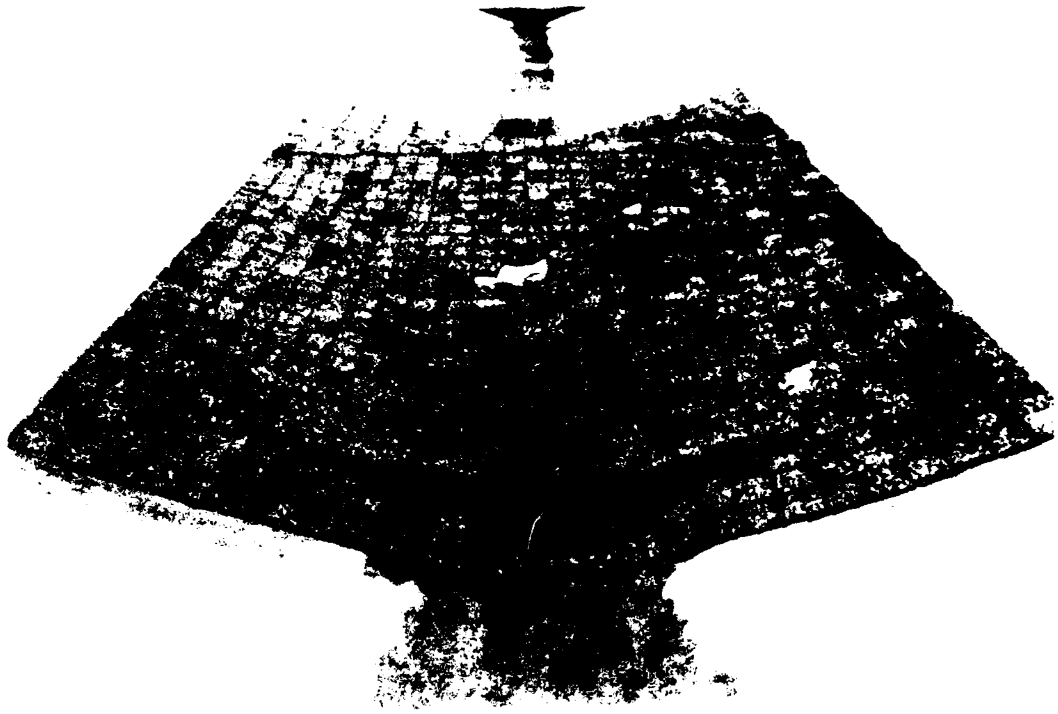


a. Test 1



b. Test 4

Photo 16. Various forms of failure of gabion structures (Sheet 1 of 2)



c. Test 6

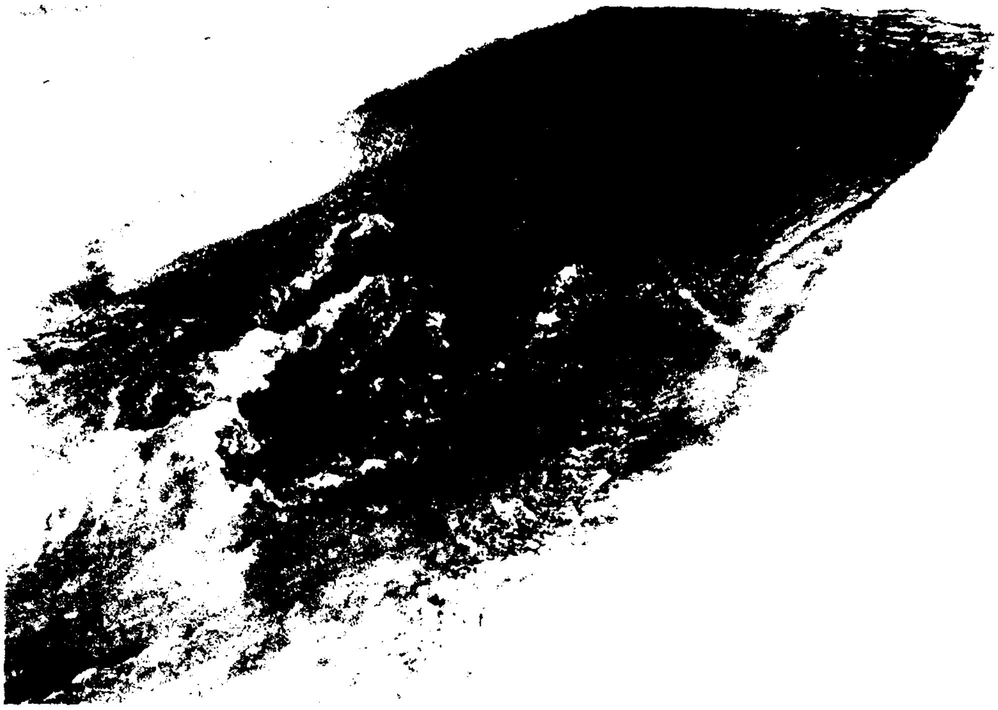
d. Test 9

Photo 16. (Sheet 2 of 2)

a. Test 4, discharge 6000 cfs

b. Test 4, discharge 9900 cfs

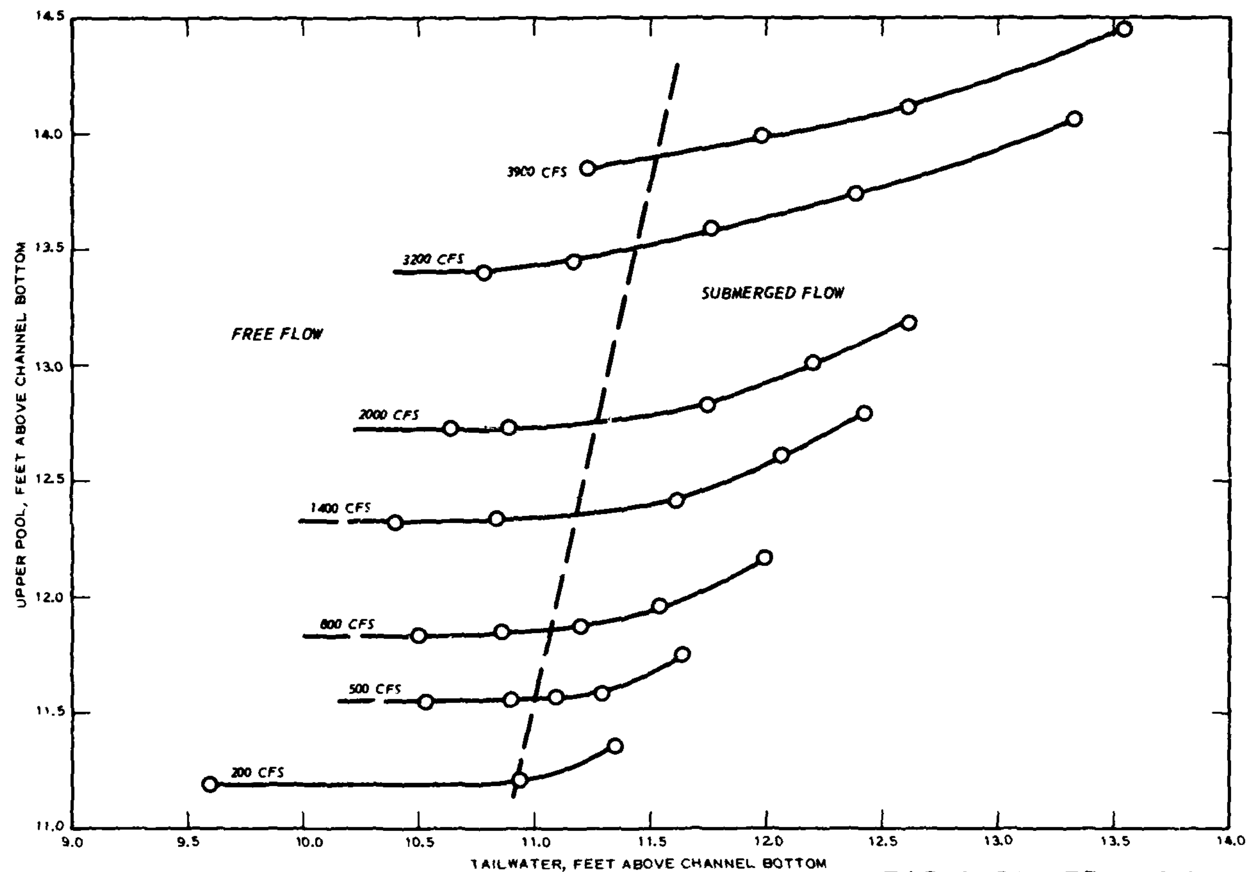
Photo 17. Various flow conditions over gabion structures (Sheet 1 of 2)



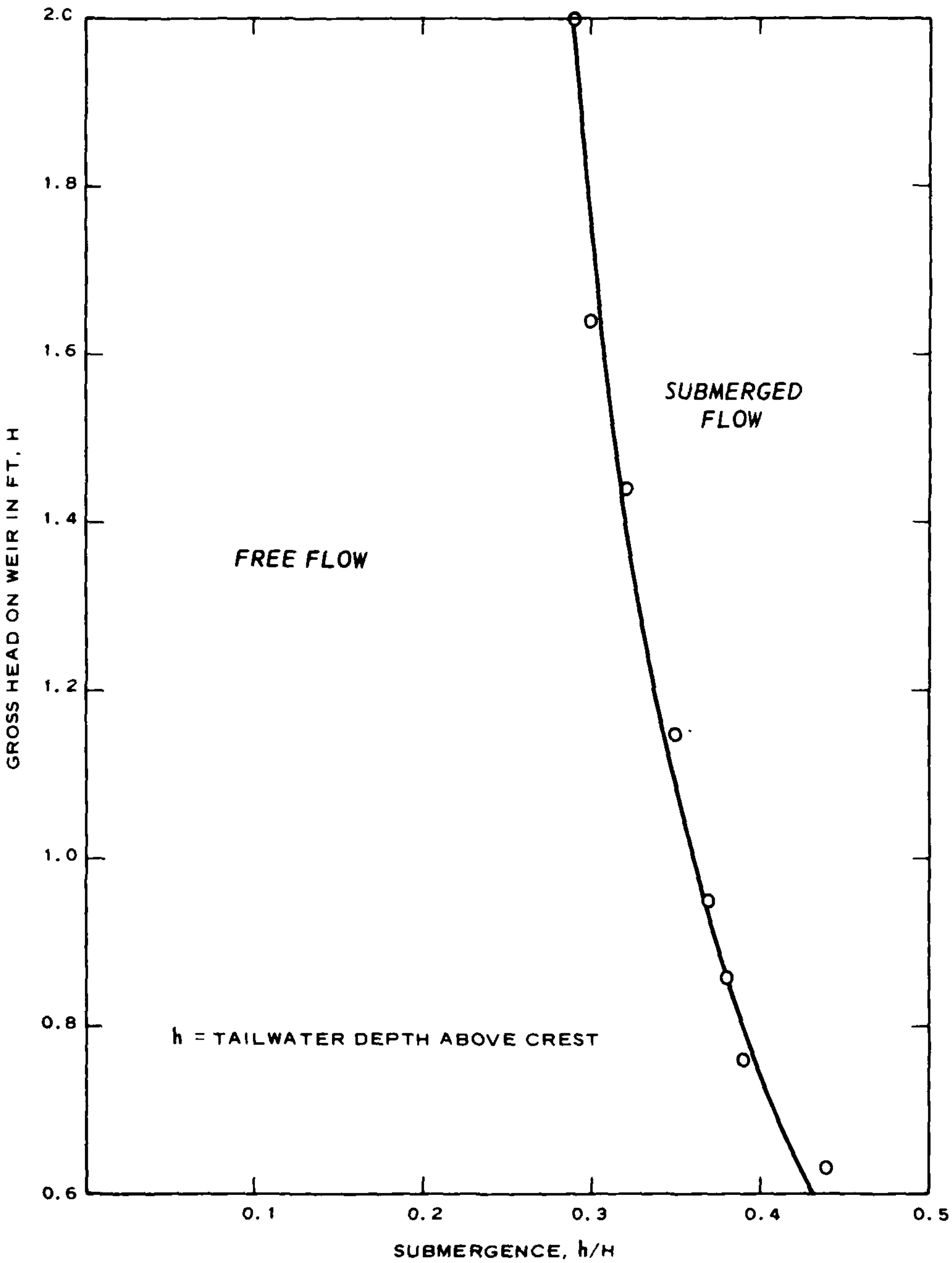
c. Test 6, discharge 6000 cfs

d. Test 6, discharge 9900 cfs

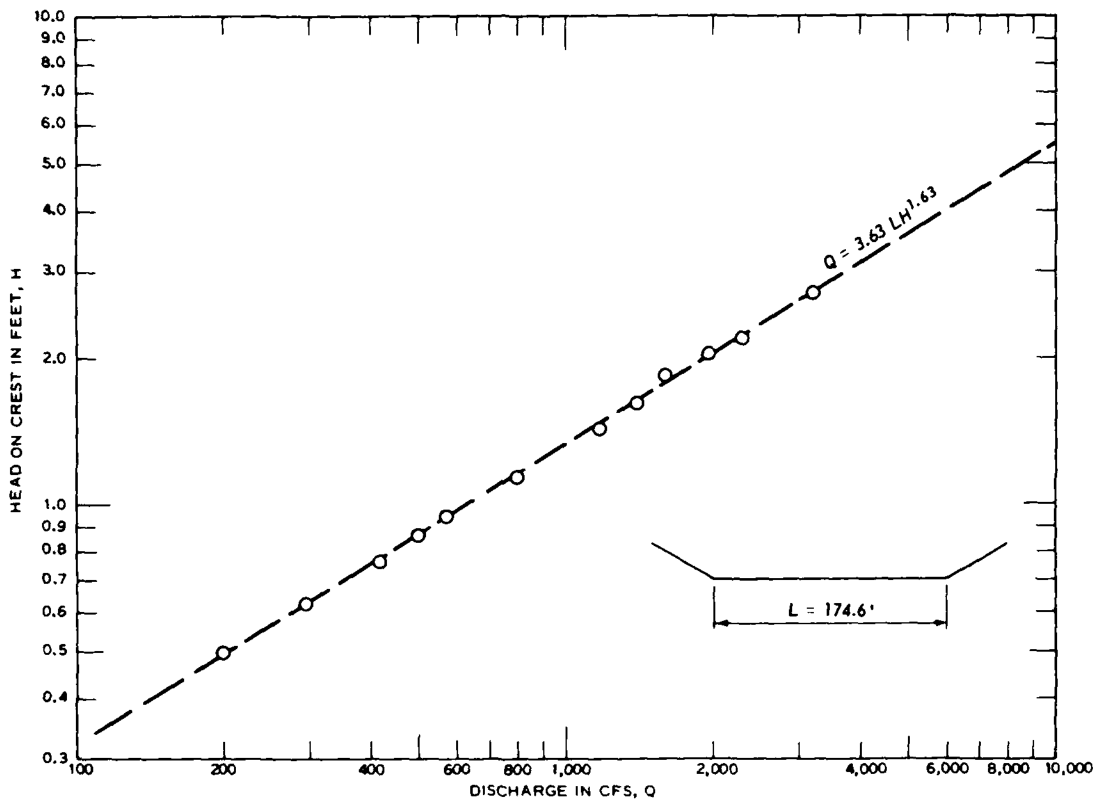
Photo 17. (Sheet 2 of 2)



BASIC CALIBRATION DATA FOR FREE AND SUBMERGED FLOW
TYPE III STRUCTURE
GATE WELL CLOSED

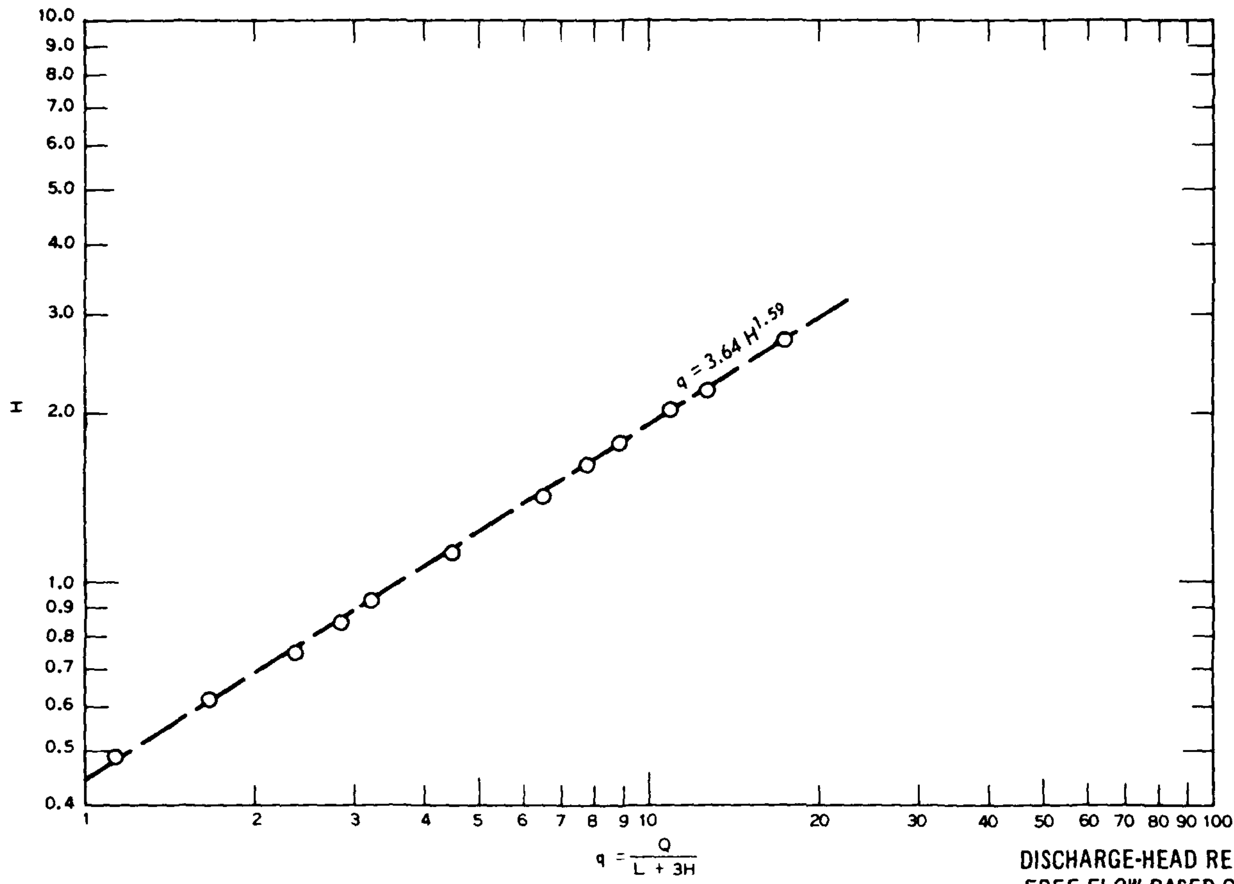


FLOW REGIMES
TYPE III STRUCTURE
GATE WELL CLOSED



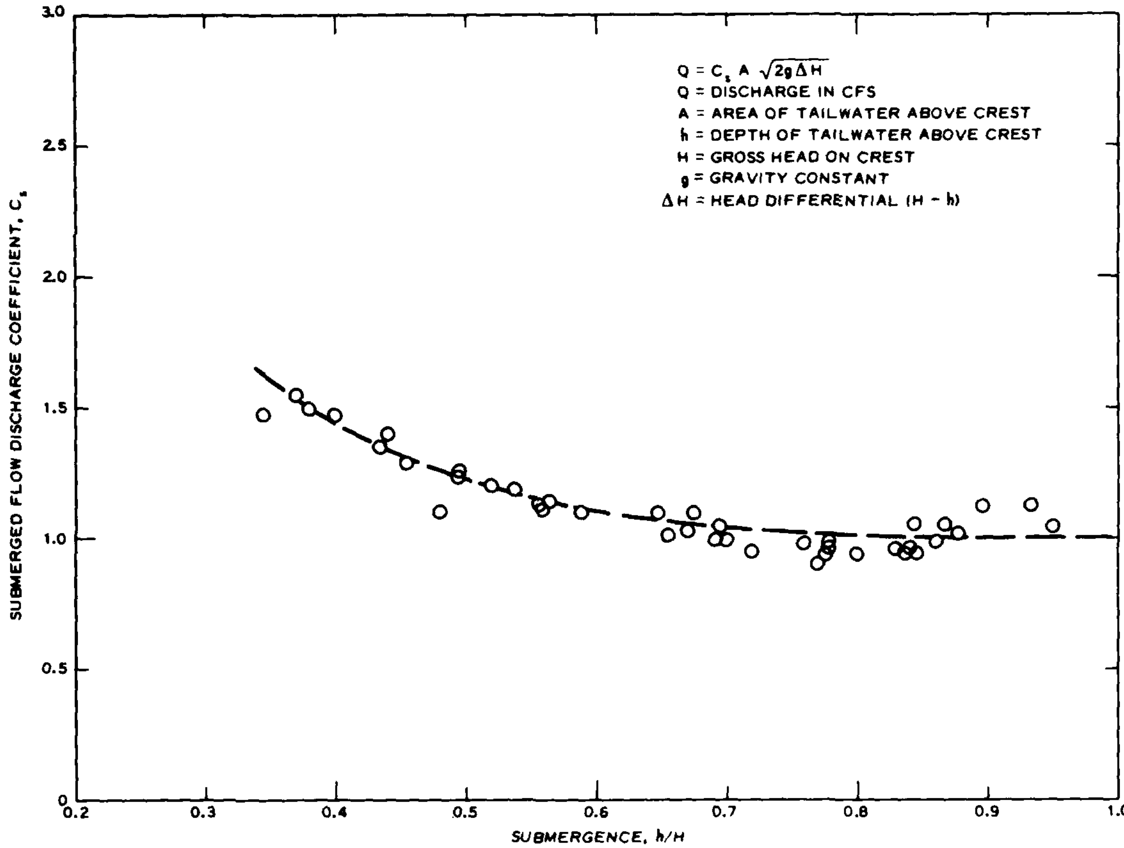
DISCHARGE-HEAD RELATION FOR FREE FLOW

TYPE III STRUCTURE
GATE WELL CLOSED



DISCHARGE-HEAD RELATION FOR FREE FLOW BASED ON AVERAGE WIDTH OF WATER

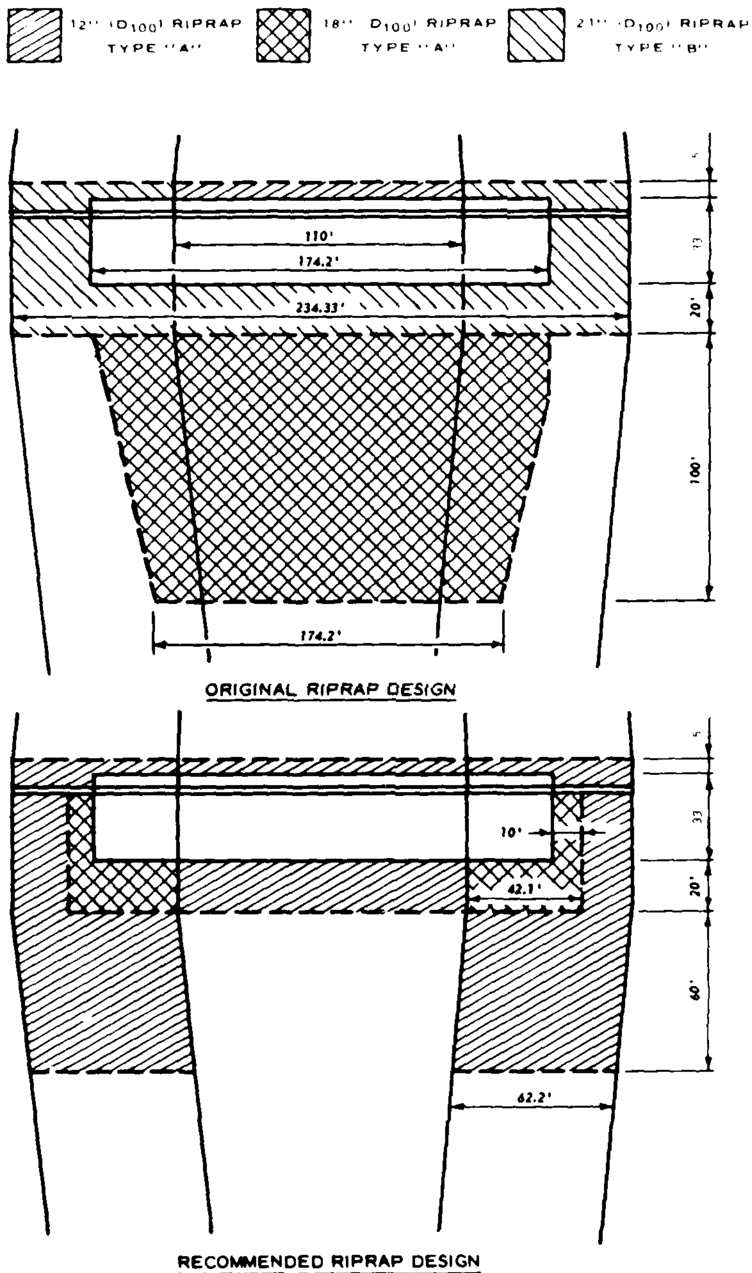
TYPE III STRUCTURE
GATE WELL CLOSED



SUBMERGED FLOW

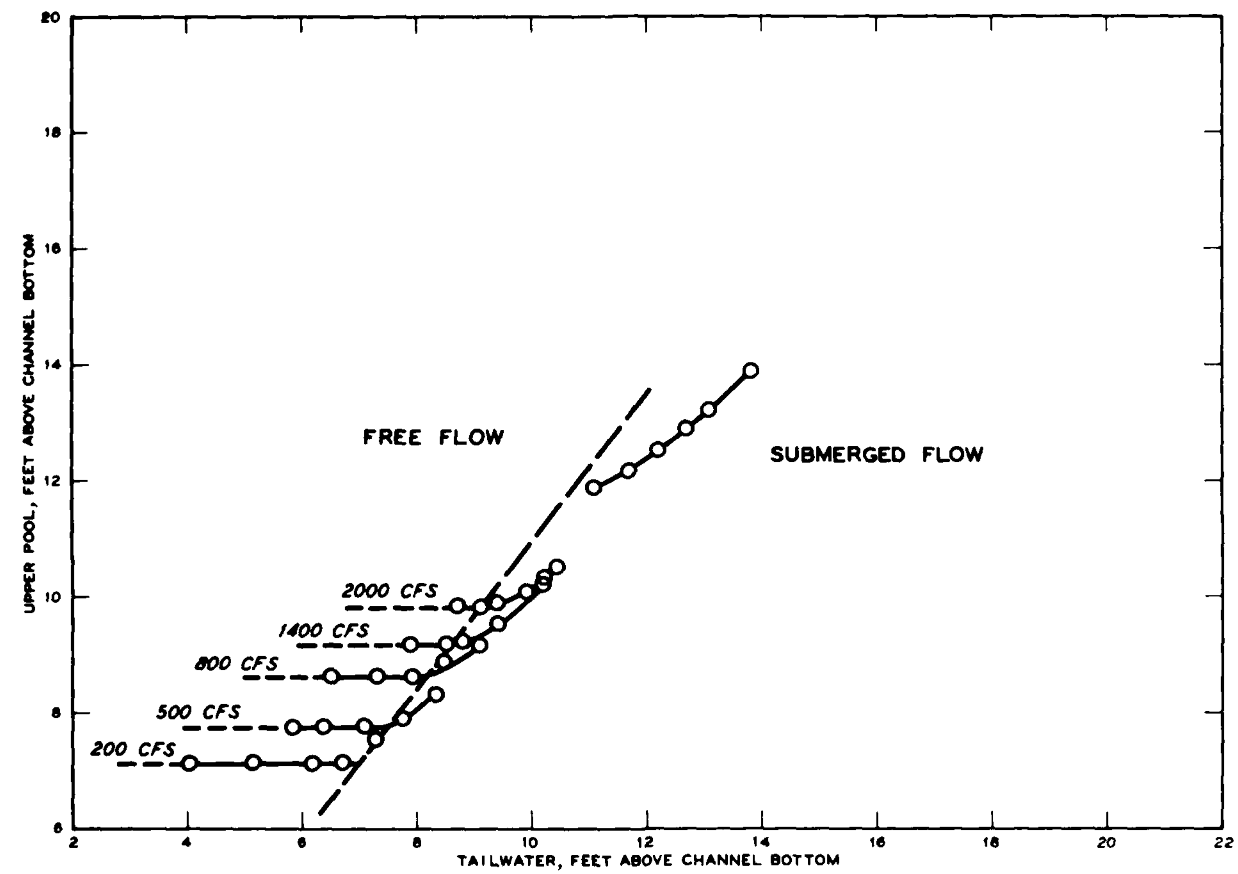
TYPE III STRUCTURE

GATE WELL CLOSED

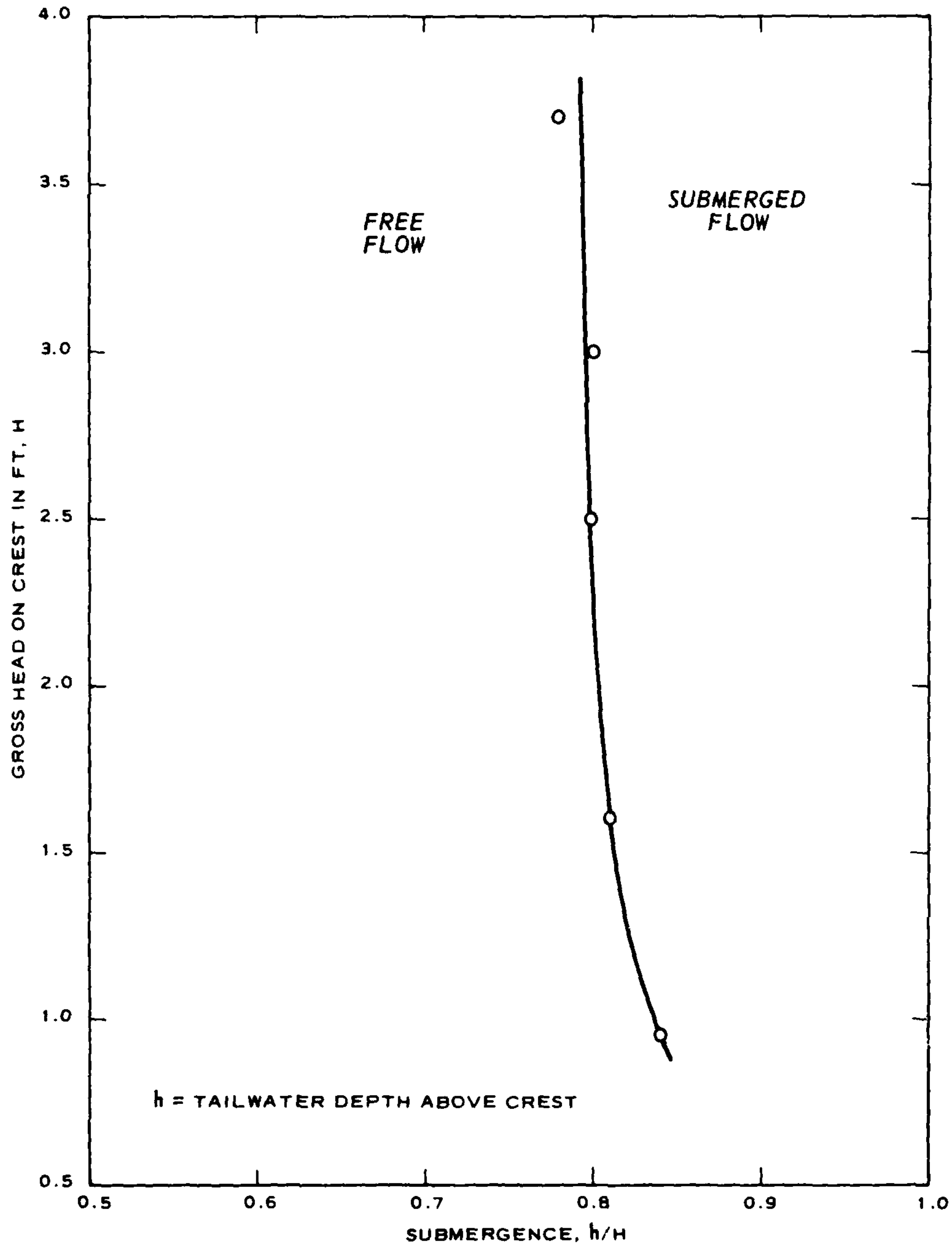


RIPRAP DESIGNS FOR
TYPE III STRUCTURE

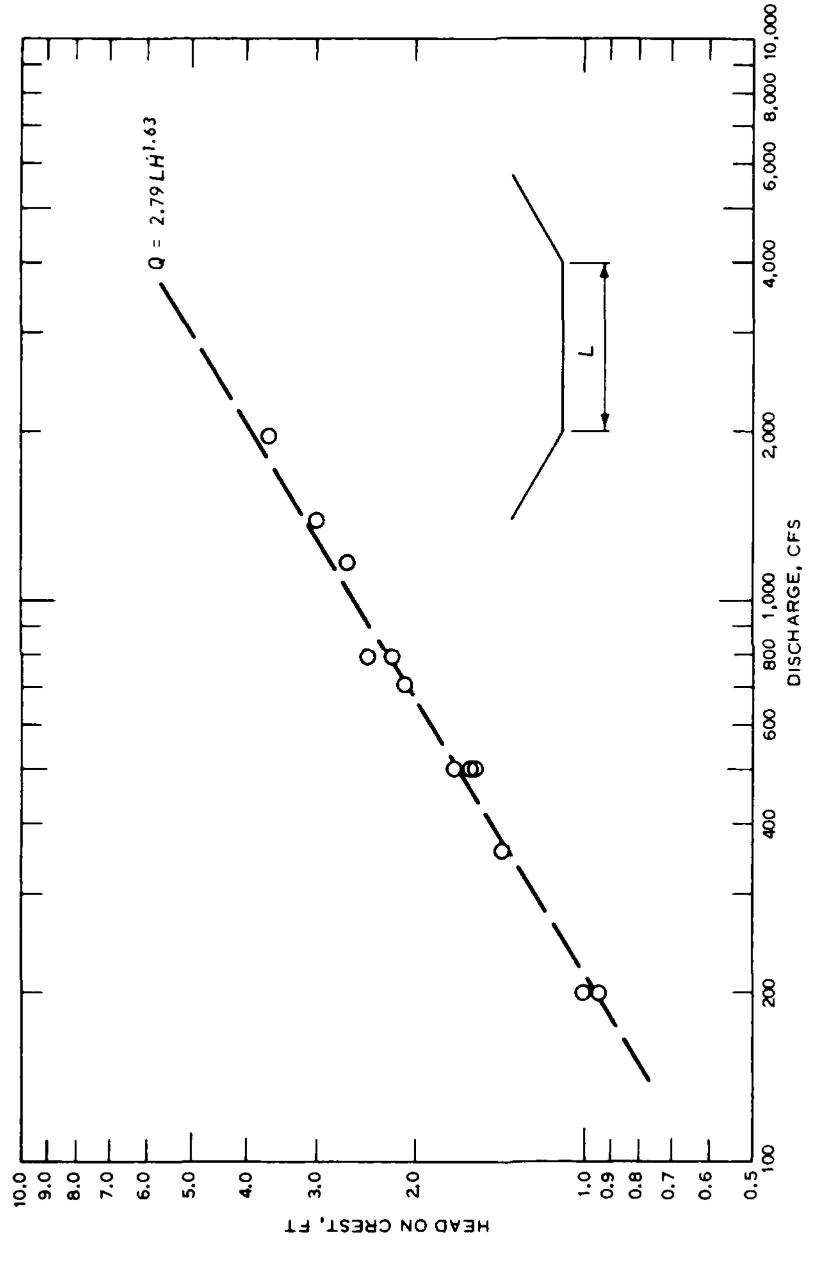
PLATE 6



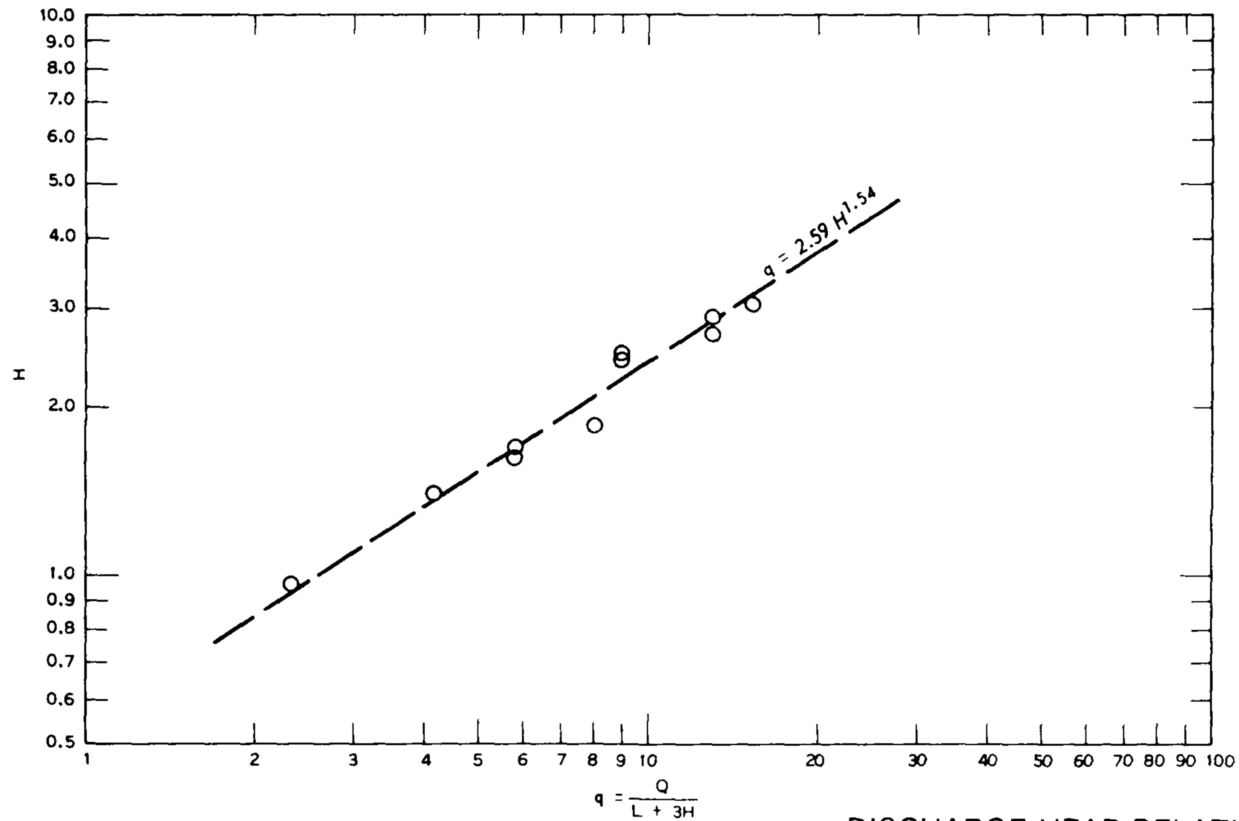
GABION STRUCTURES
BASIC CALIBRATION DATA
TYPE I STRUCTURE



FLOW REGIMES
TYPE I STRUCTURE

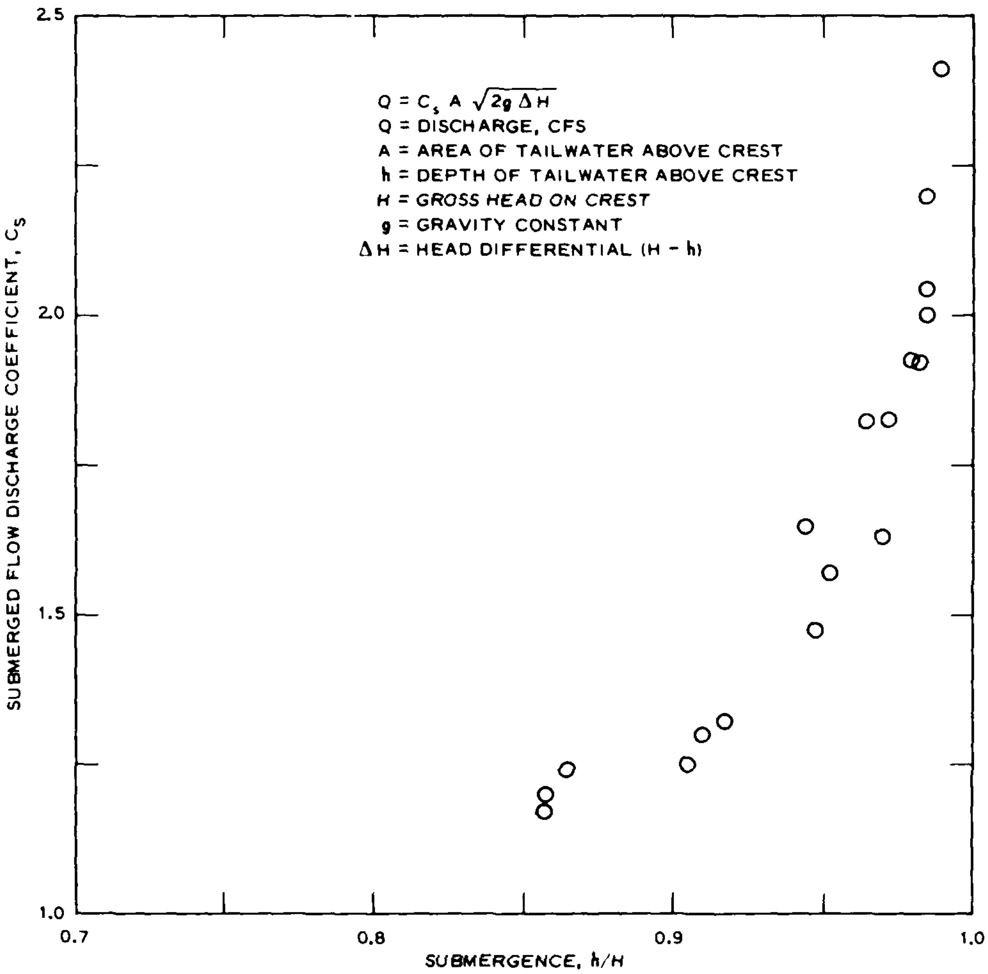


DISCHARGE-HEAD RELATION
FOR FREE FLOW
TYPE I STRUCTURE

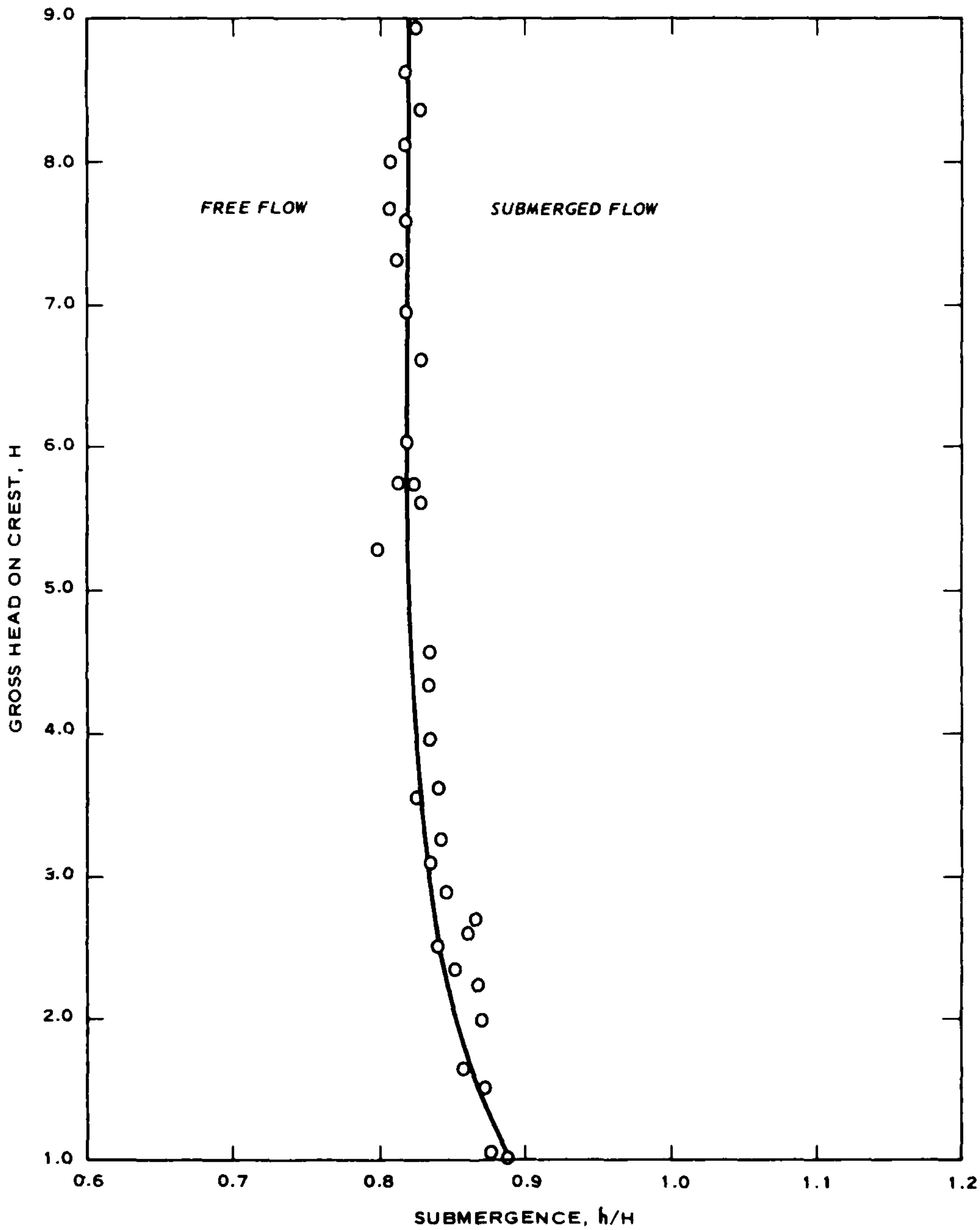


DISCHARGE-HEAD RELATION FOR
FREE FLOW BASED ON AVERAGE
WIDTH OF WATER

TYPE I STRUCTURE

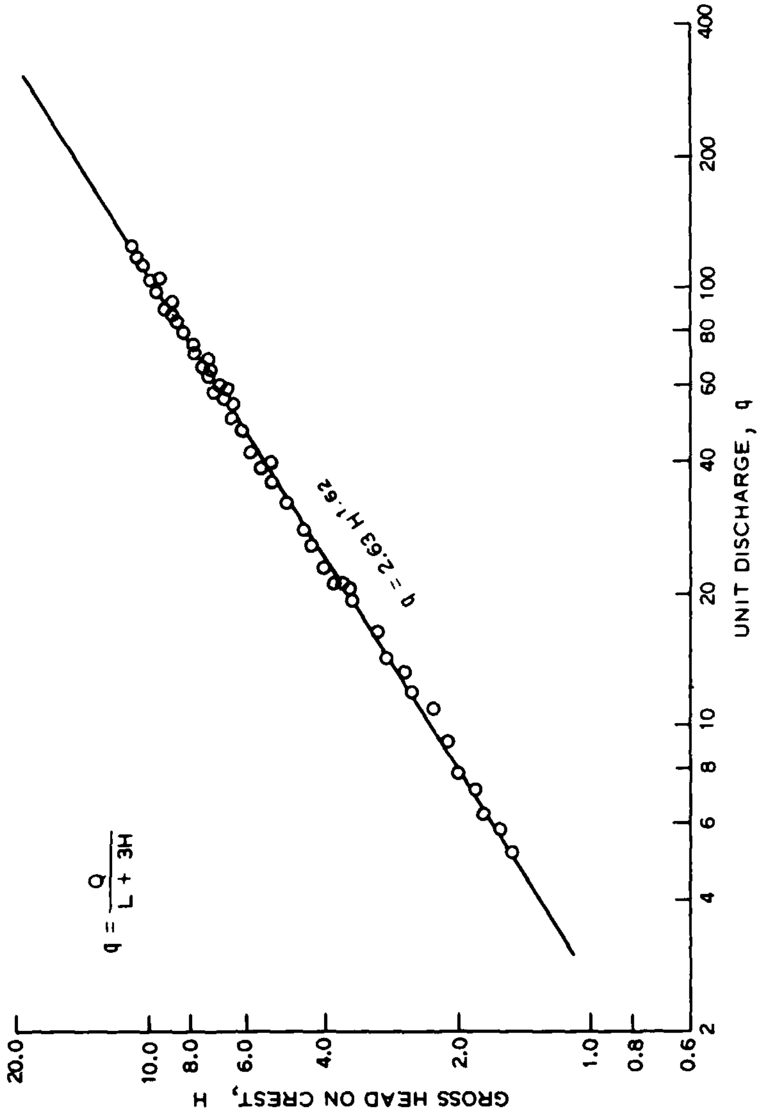


SUBMERGED FLOW
TYPE I STRUCTURE

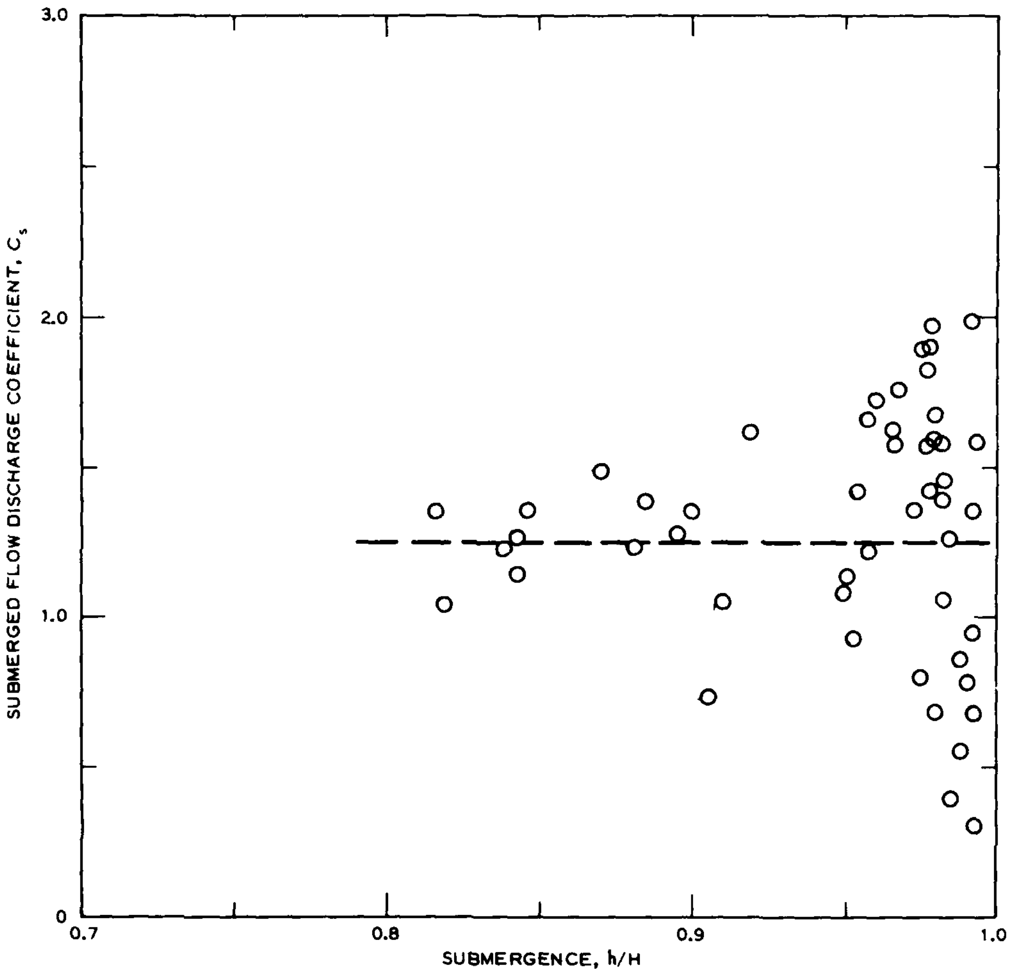


FLOW REGIMES

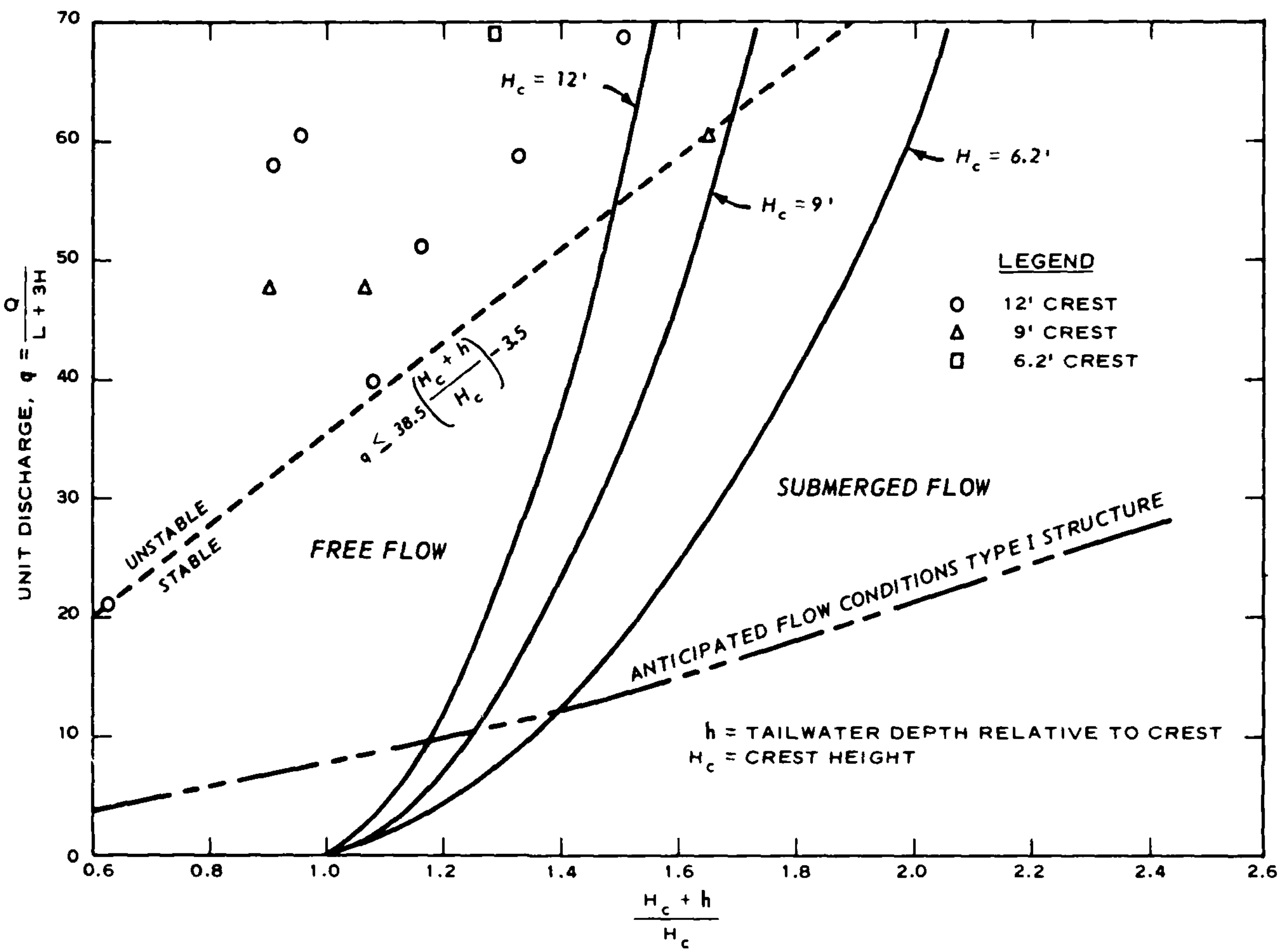
TESTS 1-9 GABION-CONSTRUCTED CONTROL STRUCTURES



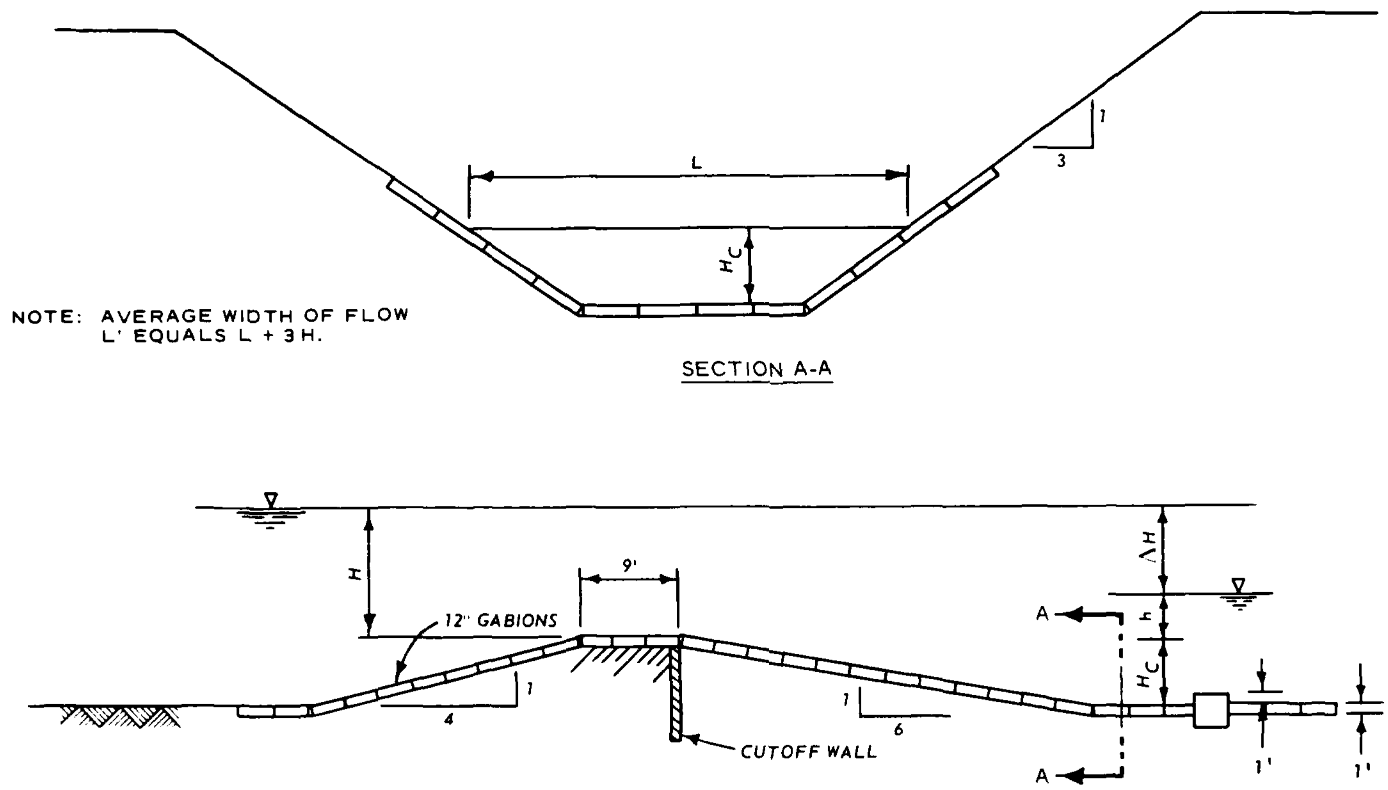
DISCHARGE-HEAD RELATION FOR FREE FLOW
GABION-CONSTRUCTED CONTROL STRUCTURES



SUBMERGED FLOW
TYPE III STRUCTURE



LIMITS OF STABILITY
GABION-CONSTRUCTED CONTROL STRUCTURES



DEFINITION OF VARIABLES
GABION-CONSTRUCTED CONTROL STRUCTURES

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Saunders, Peter A.
Channel control structures for Souris River, Minot, North Dakota : Hydraulic model investigation : Final report / by Peter A. Saunders, John L. Grace, Jr. (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station) ; prepared for U.S. Army Engineer District, St. Paul. -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1981.
24, [17] p., [8] leaves of plates : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; HL-81-3)
Cover title.
"April 1981."

1. Channels (Hydraulic structures). 2. Hydraulic models. 3. Hydraulic structures. 4. Souris River. I. Grace, John L., Jr. II. United States. Army. Corps of Engineers. St. Paul District. III. United States. Army Engineer Waterways Experiment Station.

Saunders, Peter A.
Channel control structures for Souris River : ... 1981.
(Card 2)

Hydraulics Laboratory. IV. Title V. Series: Technical report (United States. Army Engineer Waterways Experiment Station) ; HL-81-3.
TA7.W34 no.HL-81-3